Issued December 11, 1911.

U. S. DEPARTMENT OF AGRICULTURE,
FOREST SERVICE—BULLETIN 102.
HENRY S. GRAVES, Forester.

THE IDENTIFICATION OF IMPORTANT NORTH AMERICAN OAK WOODS,

BASED ON A STUDY OF THE ANATOMY OF THE SECONDARY WOOD.

BY

GEORGE B. SUDWORTH, DENDROLOGIST,

AND

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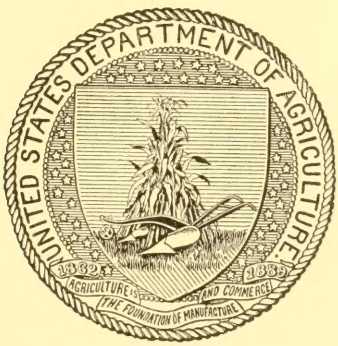

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LETTER OF TRANSMITTAL.

UNITED STATES DEPARTMENT OF AGRICULTURE,
FOREST SERVICE,
Washington, D. C., August 3, 1911.

SIR: I have the honor to transmit herewith a manuscript entitled "The Identification of Important North American Oak Woods," by George B. Sudworth, Dendrologist, and Clayton D. Mell, Assistant Dendrologist, and to recommend its publication as Bulletin 102 of the Forest Service.

Respectfully,

HENRY S. GRAVES,
Forester.

Hon. JAMES WILSON,
Secretary of Agriculture.

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THE IDENTIFICATION OF IMPORTANT NORTH AMERICAN OAK WOODS.

NEED FOR MEANS OF IDENTIFYING THE VARIOUS OAKS.

This bulletin, the first of a series dealing with the distinguishing characters of North American woods (exclusive of Mexico), is prepared as an aid in the identification of the principal oaks, which have received first consideration because they are so widely useful. Other groups of woods are to be taken up in order of their commercial importance.

While this work is designed for the assistance of all students of woods, special effort has been made to render it helpful to manufacturers of lumber, architects, builders, and other wood users. It is felt, however, that wood users are likely to derive the greatest assistance from the illustrations, by comparing them with the woods to be identified, rather than by trying to use the key, which is intended mainly for trained students. With the conviction that a very large number of wood users can be helped to recognize at least a great many woods, the endeavor has been to present for each wood all available simple characters, carefully combined with such of the less easily observed, finer distinctions as the ordinary student can reasonably be expected to master.

The wood user's need of a reliable means of recognizing commercial woods has become greatly emphasized in recent years because of the enormous demand for standard kinds and species of woods. This increased use is necessitating, in some cases, the substitution of similar or entirely different woods for many of the well-known and long-used ones, the supplies of which no longer meet the demand. Some of the substitutes offered are as good as the standard timbers, while others are inferior to them. However this may be, the frequent discovery by consumers that they have not received the woods ordered has led to a great many difficulties and to serious controversies involving expensive lawsuits. In many instances manufacturers believe that in substituting, for example, the woods of several different species of the white oaks for that of the true white oak (*Quercus alba*) they are doing no injustice to purchasers, and this belief is reasonably supported by facts. Much depends upon the

use made of the timber. No one could deny that for some purposes the woods of cow oak (*Quercus michauxii*), overcup oak (*Q. lyrata*), post oak (*Q. minor*), bur oak (*Q. macrocarpa*), swamp white oak (*Q. platanoides*) are as good as that of white oak. But the substitution, for example, of the somewhat similar black and red oaks for true white oak is less easily defended, because these substitutes are very different in quality from any of the white-oak woods.

With the numerous oaks, therefore, as with many other woods the consumer has occasion to distinguish, such superficial characters as color, feel, odor, hardness, weight, etc., can not be depended upon alone as distinctive, because they vary not only with the age of the tree but also according to the soil in which the tree grew and the season and manner of cutting. The butt log differs from the top log, the heartwood from the sapwood, and the wood of a rapidly grown tree from that of a less rapidly grown one of the same species.

While the practical woodworker recognizes the woods with which constant work has made him familiar, his knowledge of other woods is necessarily limited. Confronted with the necessity of distinguishing the few oak woods he knows from a larger number of different species, the characters he has long and safely relied upon are often insufficient because they may be common to the wood of some of the oaks with which he is unfamiliar. Thus a carefully selected, well-seasoned piece of water oak (*Q. nigra*) may be so similar in color and general appearance to some grades of white oak as to deceive not a few unacquainted with the structural characteristics of all our oaks.

Another difficulty that may be encountered by one who depends entirely upon an empirical knowledge of woods is to prove his convictions regarding the identity of a wood. For want of exact knowledge of the anatomical characteristics of the wood in question, he can only insist upon his opinion. It happens in actual practice that one inspector passes as white oak a shipment composed of white oak, black oak, and red oak, and his judgment is challenged by another inspector, yet in such an event neither is able to do more than assert his opinion.

It must not be understood that a study of the structural characters of woods always renders identification easy. It is sometimes extremely difficult to find characters that distinguish the woods of closely related trees, which may be abundantly distinct in their flowers, fruit, and foliage. It is comparatively easy to point out simple characters which distinguish oak from other woods. Moreover, it is not difficult to find characters that will separate the white oaks (annual fruiting species) from the black and red oaks (biennial fruiting species). The task, however, of pointing out easily observed distinctions that can be relied upon to separate the woods of different species of white oaks, black oaks, and red oaks is difficult, and, in a few instances, impossible without the aid of the high magnifying power

of a compound microscope. This is because some of the minute structural characters, easily demonstrated when greatly magnified, can not be seen under the low magnifying power of a simple pocket lens. However, the need of high magnification is confined chiefly to little-known species, with which the practical wood user is not likely to meet.

Of the approximately 300 different species of oaks known in the world, about 53, exclusive of varieties and hybrids, occur within the United States. Three or four of these are mere shrubs, while the remainder are small, medium, or large sized trees. The 35 oaks described in this publication include all of the commercially useful ones and a number of other species, the woods of which are likely to become more or less useful in the future. The remaining 15 species are excluded from the present treatise because their woods are of inferior quality or the trees occur in such limited quantities as to be of little or no economic importance.

The illustrations accompanying this bulletin were made by outlining with a pen photographs of enlarged transverse sections [1] of the wood, and they show the exact appearance of each section as seen under a microscope magnifying the structure 20 times its natural size. The illustrations are so arranged that the pith rays run up and down, and the outside of the annual layer of growth stands toward the top of the page.

Structural characters of the wood having the most distinct value for identification are confined principally to transverse sections, in which the size, form, arrangement, and other relations of elements are clearly shown. The greatest aid will be derived, therefore, by a careful comparison of the smoothly cut end of a block with the illustrations. Radial and tangential sections were also studied for the purpose of discovering any distinctions which these views of the wood might offer. A great many measurements of the fibers of each species, to be seen only in these sections, were taken, and their average length computed. These are shown in Table 1 on page 56.

PREPARING WOOD FOR EXAMINATION.

In preparing a piece of wood for examination with the pocket lens it is necessary to cut a smooth surface approximately at right angles to the vertical axis of the specimen. If the knife is not sharp the surface of the cut will be rough and show but little of the characteristic structure. With a specimen carefully prepared in this way, the observer will be surprised to see how much of detail in the

[1] Preparatory to sectioning, small blocks of wood, of about one-half cubic centimeter, were first boiled in water until they were thoroughly saturated and partially softened, after which they were placed in a dilute solution of hydrofluoric acid for about 10 days in order to dissolve out the silicates. After thoroughly washing the blocks in water, microscopic sections, 8 to 12 micro-millimeters thick, were cut from them with a microtome. These sections were then double-stained in safranin and Delafields hæmatoxylin and mounted, in the susual way, in balsam, on glass slides.

wood structure a small pocket lens reveals. By using the most powerful form of an aplanatic triplet pocket lens a still better view of the structure can be had.

GROSS STRUCTURE OF OAK WOODS.

PRINCIPAL PARTS OF THE OAK STEM.

Many are familiar with the principal parts of an oak stem as shown on a freshly cut stump. These parts comprise, first, the bark; second, the sapwood; third, the heartwood; and fourth, the pith. Throughout the wood of the stem there are more or less distinct and irregularly concentric rings of varying thickness. These are annual rings of growth. Running from the pith or center of the stem to the bark are spoke-like lines, which are pith rays. These different tissues afford distinctive features as they appear in close union, and are therefore briefly described below, so that the reader may become familiar with their characters and arrangement as a means of classifying and identifying different species.

SAPWOOD AND HEARTWOOD.

A transverse section of the stem of an old oak tree shows two distinct zones. The outer portion called sapwood (alburnum) (fig. 1, *s. w.*) is of a light color and consists of a more or less thick zone immediately beneath the bark (fig. 1, *b.*); the inner portion known as heartwood (duramen) is generally darker colored (reddish brown to yellowish brown), forming a much harder and more durable mass. The width of the heartwood increases year by year, but that of the sapwood remains approximately the same, for an inner layer of sapwood becomes transformed annually into an outer layer of heartwood. This difference between the sapwood and heartwood is always quite evident in hardness and color. The heartwood is lifeless and serves the tree only as a mechanical support, while the sapwood alone is the living part of the tree and the part in which all vital activities take place. The heartwood owes its darker color and its hardness and durability to the infiltration of dark-colored chemical substances, such as gums and resinous substances, which impregnate the cell cavities and frequently fill up the cavities of the wood fibers.

The sapwood of the different species of oaks varies considerably in width; for example, it is thin in red oak and thick in Spanish oak. It varies also in different trees of the same species, depending upon the soil, light, and climatic conditions as well as on the general health of the trees. Although color and thickness of sapwood are sometimes useful characters in distinguishing different woods, frequently they can not be depended upon. Moreover, a large propor-

tion of the sawed oak timber reaching the markets consists wholly of heartwood. For these reasons the structural characters of the heartwood, not different, however, from those of the sapwood, have been mainly relied upon as a basis for classification.

ANNUAL RINGS OF GROWTH.

All North American oaks exhibit in transverse sections more or less clearly the so-called zones or annual rings of growth (fig. 1, *a. r.*).

FIG. 1.—Transverse section of chestnut oak (*Quercus prinus*); *b.*, bark; *s. w.*, sapwood; the darker inner portion is heartwood; *a. r.*, annual ring; *p. r.*, pith ray. Natural size.

In rapidly growing trees these layers are distinctly marked, while in those from dry arid regions of the West, where the growing season is short, or often restricted to periods of rain, the layers are so narrow that they appear to be absent or at least obscured by the mere succession of inconspicuous rings composed chiefly of pores (fig. 2). The width of the rings varies greatly with the age of the tree, also in different parts of the same tree and in different trees of the same species. Trees growing in the open develop larger crowns, and

consequently manufacture a greater amount of plant food, than trees in a dense forest. The increase in foliage is accompanied by an increase in the rate of diameter growth. It follows, therefore, that trees in the open with plenty of growing space develop wide annual rings, while those in the forest with limited space for crown development often form very narrow rings.

The number of growth rings shown in a transverse section of an oak, or any other tree grown in a temperate climate, in general indicates the age of the tree, since normally one ring or layer of growth is added to the thickness of the trunk and its branches each year. There are, however, frequent influences which disturb this general

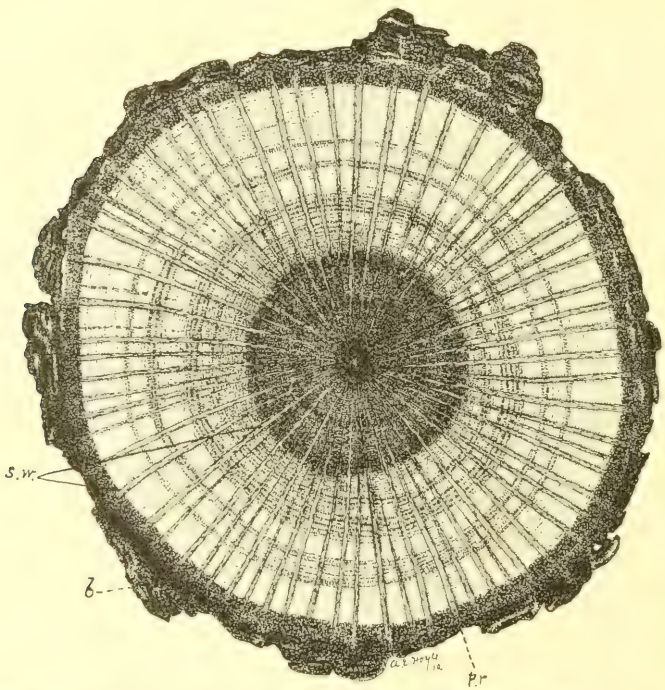

FIG. 2.—Transverse section of (California) blue oak (*Quercus douglasii*); *b.*, bark; *s. w.*, sapwood; the dark inner portion is heartwood; *p. r.*, pith ray. Natural size.

regularity, such as drought or the destruction of the leaves by insects during the growing season. The result is a temporary cessation of growth, and in such a case trees may again put forth a new set of leaves and start growth anew during the same season. This usually results in the formation of another ring of pores (the characteristic growth at the beginning of the season) similar to the normal early wood. This second or newly formed layer is called a "false ring."

Annual rings of growth consist of an inner and more porous portion known as early wood (fig. 32, *e. w.*) and an outer and denser portion called late wood (fig. 32, *l. w.*). These more or less sharply

contrasted parts of the annual rings are a result of the development of a gradually dimishing number of large vessels during the latter part of the season's growth. The denser portion, therefore, encases the more porous part, or early wood, which contains elements with larger diameters and thinner walls. These elements are called vessels, which serve as conducting tissue. The dense late wood, which ordinarily forms the greater part of the annual ring, is composed largely of closely packed, thick-walled wood fibers which give the wood strength, weight, toughness, and elasticity. The wood of slowly grown oaks, and particularly that of old trees, is often exceedingly "brash," because it contains a very large proportion of early (porous) wood.

The proportion of late to early wood is usually greater in fast-growing than in slow-growing trees. This is true especially of the wood formed near the base of the stem, where it is denser and heavier than that in any other portion of the tree. There is less early wood formed at the base of the stem than farther up, because growth commences nearly a month later at the base. The strongest, densest, and toughest oak timber is that grown in the open, where the full enjoyment of side light produces wide rings.

PITH.

A transverse section of the stem of an oak exhibits a light-brown speck in the center commonly known as the pith, which is quite small and does not increase in size as the tree grows older. (See center of figs. 1 and 2.) The cells composing the pith are thin walled, usually of uniform diameter, and gradually become emptied of their contents. In some oaks these elements, technically known as parenchyma cells, continue to live for a number of years, later becoming lignified and thickened with age, so that it is often difficult to detect the pith in stems of old trees. In transverse section the pith of most oaks is pentagonal in outline. This character is useful in distinguishing oaks as a group from other woods.

PITH RAYS.

Pith rays constitute the spoke-like lines to be seen more or less conspicuously on the transverse section of the oak stem (figs. 1 and 2, *p. r.*). They form the so-called "silver grain" well known among carpenters. The large (primary) pith rays are merely spokes, as it were, joining the pith and bark. Each spoke is from a few to 25 or more ray cells in width, and from 100 to 600 or more cells in height (fig. 3, *p. p. r.*). Each succeeding year other rays are formed, which extend from the point where they originate to the periphery of the stem. These are called small (secondary) pith rays because

they started later in the life of the tree, but they serve the same purposes and bear the same relationship to other tissue of the stem as the large pith rays, except that they do not extend inward to the pith (fig. 3, *s. p. r.*). The small rays are seldom more than one cell wide, but are from a few to 20 or more cells high. On a radially split surface of oak wood the large pith rays may be seen with the unaided eye as horizontal bands traversing the wood from within outward; the small rays can not be seen with the unaided eye.

The presence of two kinds of rays in the woods of all North American oaks furnishes another helpful generic distinction. Investiga-

FIG. 3.

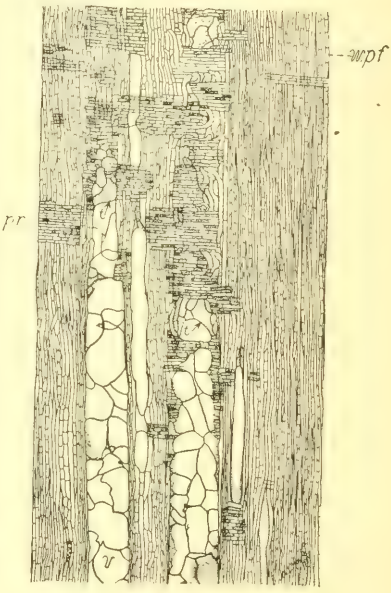

FIG. 4.

FIG. 3.—Spanish oak (*Quercus digitata*). Tangential section showing large (*p. p. r.*) and small pith rays (*s. p. r.*) magnified about 20 diameters.

FIG. 4.—Blackjack (*Quercus marilandica*). Radial section showing pith rays (*p. r.*) magnified 20 diameters.

tions show, however, that the characters of the pith rays in oaks are not sufficiently constant to distinguish the different species. The number of pith rays is largely dependent upon the age of the tree, and they are most abundant in wood of the first layer of growth. Proceeding from this toward the bark they gradually diminish in number per unit area for a certain period of years, and then again, later in the life of a tree, they commence to increase in number. Moreover, different individuals of the same species show a marked variation in the number of pith rays. With reference to the number of rays for the different species of oaks, the figures obtained by actual counts are exceedingly variable. Again, the height of the pith rays in the same individual and in different individuals of the same

species is so variable that it can not be accepted as a trustworthy mark of distinction. As the trees grow older the pith rays gradually increase in height. Evergreen oaks, and particularly very slow-growing species or those growing on dry arid soil, develop rather low and wide rays, which have blunt ends above and below. This applies particularly to oaks of the Rocky Mountain and Pacific slope regions. The deciduous oaks, growing in moist, alluvial soils, develop high and narrow pith rays which have more or less acute ends above and below. This applies particularly to the eastern oaks (compare figs. 1 and 2). For a difference in comparative width of pith rays in the two arbitrary groups referred to above see figures 1 and 2.

MINUTE STRUCTURES OF OAK WOODS.

The minute elements which make up the wood of oaks will be described separately, in order to present a clear general view of the part they play in the composition of the wood. Size, shape, relative proportion, and grouping of the elements are more or less characteristic in all woods, and a clear idea of these elements can be obtained only by a study of the transverse, radial, and tangential sections under a compound microscope. Five different kinds of elements can then be distinguished; namely, vessels, tracheids, wood fibers, wood-parenchyma fibers, and pith-ray cells.

VESSELS OR PORES.

The vessels differing in size and arrangement may be seen with the unaided eye in a transverse section of the wood of both deciduous and evergreen oaks. These vessels, commonly known as pores, and technically as tracheæ, make up chiefly the inner and more porous part of the annual ring of growth. They vary from less than 0.1 to more than 0.6 of a millimeter [1] in diameter and are composed of tube-like segments arranged longitudinally end to end; the cavities of the vessels communicate directly with one another, while the adjoining obliquely formed ends are perforated by horizontal pits (fig. 5a, *a.*), or are completely absorbed (fig. 5, *a.*) so that the rows of cells or vessel segments finally form long, continuous tubes. These oblique cross walls (fig. 5, *c. w.*) between the vessel segments not infrequently have scalariform (ladder-like) perforations (fig. 5a, *a.*). Individually the segments are often short and barrel-shaped, though they usually have rather obliquely formed end walls which always face toward the pith rays. The segments in late wood are about twice as long as they are wide, but in the early wood their diameter sometimes exceeds their length. In a longitudinal section of oak wood they appear as minute

[1] One millimeter is equal to about one twenty-fifth of an inch. The metric system is used in this work in order to avoid large fractions.

channels. The vessels which are arranged in radial rows (transverse section) in the late wood have a successively smaller diameter than those formed earlier, and with this gradual diminution in diameter

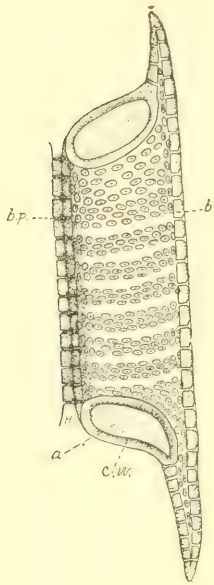

Fig. 5

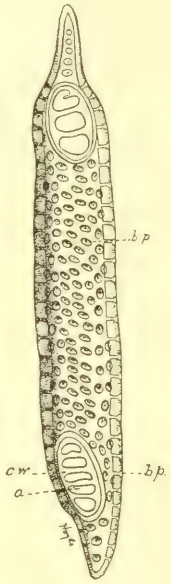

Fig 5a

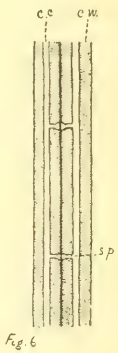

Fig. 6

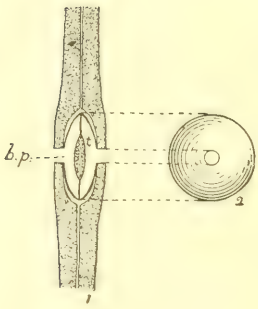

Fig 6a

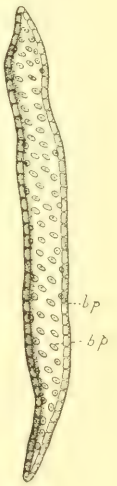

Fig 7

FIG. 5.—Vessel segment showing oblique cross walls (*c. w.*) completely absorbed at *a;* *b. p.*, bordered pit. Magnified about 100 diameters.

FIG. 5a.—Vessel segment showing oblique cross walls (*c. w.*, partly absorbed); *a*, scalariform (ladder-like) perforations; *b. p.*, bordered pits. Magnified 100 diameters.

FIG. 6.—Longitudinal section of portions of two wood fibers showing simple pits (*s. p.*); *c. w.*, cell wall; *c. c.*, cell cavity. Magnified about 100 diameters. (See also fig. 8.)

FIG. 6a.—1. Longitudinal section of a bordered pit (*b. p.*); *t*, torus. 2. Surface view of pit; corresponding regions are connected by dotted lines. Magnified about 500 diameters.

FIG. 7.—Tracheid showing bordered pits (*b. p.*). Magnified about 75 diameters.

there is generally a corresponding increase in the thickness of the walls of these elements, a factor which adds mechanical support to the tree. The size and arrangement of these small vessels in the late wood also afford, to some extent, distinctive features.

The side walls of vessels become sculptured or pitted at maturity, and the commonest form of sculpture is the result of small areas in the walls called pits remaining unchanged during the thickening process called lignification. These unthickened portions may be seen with the aid of a microscope in a longitudinal section of oak wood. The pits are of two kinds, simple and bordered. A simple pit is a very small thin portion of the cell wall, forming a short, regular, and radially directed canal within the cell wall (fig. 6, *s. p.*). A bordered pit is formed in a similar manner, but the walls of the canals always make a distinct angle, thus leaving the short canal wide on the outside and narrow toward the center of the cell (fig. 6a, *b. p.*). Pits are shallow, depending upon the thickness of the cell walls, while in outline they are elliptical, elongated, or rarely rectangular. In a few cases they are so extended as to form thickened ridges between the pits and appear like the rungs of a ladder; hence the name scalariform markings. This mode of thickening is sometimes seen in the sapwood of evergreen oaks.

After vessels lose their sap and the air in them is rarefied, tyloses (very delicate partition-like walls) begin to form and to block up the cavities, rendering the heartwood impervious, or nearly so, especially in most species of the white oak group, to the entrance of fluids. Tyloses consist of parenchymatous (pith-like) tissue (fig. 4, *t.*) which has been forced out of the swelling (turgescent) adjacent thin-walled pith-ray cells or wood-parenchyma fibers into the lumina or channels of the vessels. The thin membranes (original, unthickened portions of cell wall) within the bordered pits, which separate the contents of the adjacent parenchyma cells, are ruptured by the swelling of the pith-ray cells. This parenchymatous tissue commences to grow very rapidly and in a short time fills up the cavities of the vessels. Tyloses are particularly abundant in wood of oaks belonging to the white oak group, and not infrequently serves to separate the white from the black oaks.

TRACHEIDS.

Tracheids (fig. 7) are usually found immediately adjoining the vessels. They are slight modifications of the wood fibers (described below), and differ from them in having thin walls with numerous more or less narrow and oblique or horizontal bordered pits. These pits occur irrespective of whether the contiguous elements are vessels, tracheids, or wood fibers. Tracheids are single fiber-like elements, and are, therefore, easily distinguished, whereas vessels are formed by a fusion of cells placed end to end. In transverse sections it is more difficult to separate them from the very small vessels. The ends of these tracheids are often curved, especially if the tracheid terminates immediately above or below a pith ray. They also have the

form of barbed hooks as seen occasionally in the wood of *Quercus wislizeni* and *Q. virginiana*. Tracheids are not referred to in the description of different species of oak wood, for the reason that they are not distinctive features.

WOOD FIBERS.

Wood fibers (fig. 8a) are very fine, thread-like cells, which compose chiefly the dark, dense outer portion of the annual ring of growth. They resemble the tracheids, though they are longer and sometimes have walls so thick that scarcely any cell cavities (fig. 8a, *c. c.*) remain. Wood fibers may be divided into two classes: First, those that are unsegmented and either have no pits at all or only a few partially developed simple pits; and second, those that are segmented and have simple pits in their walls. The segmented wood fibers are found very rarely in the wood of oaks, being restricted mainly to the wood of *Quercus garryana*, here present in an intermediate form of element between wood fibers and wood-parenchyma fibers discussed later. The narrow, thick-walled, and unsegmented wood fibers make up the greater portion of the mass of the wood of oaks (fig. 8). In *Quercus lyrata* wood fibers with wide cavities and rather thin walls form the greater part of the late wood, which accounts for its light weight and softness. Thick-walled, compactly arranged elements render the wood heavy, as in the case of most evergreen oaks. This is particularly true of the live oaks, *Quercus chrysolepis* and *Q. virginiana*. The cavities of the wood fibers are widest in *Q. catesbæi*, *Q. lyrata*, *Q. nigra*, and *Q. phellos*. On this account the wood of these oaks is softer and is worked more easily than that of the other species. The narrowest or thinnest wood fibers are found in *Q. minor* and *Q. platanoides*. The average length of wood fibers of all the North American oaks is approximately 1.3 [1] millimeters (about $\frac{1}{20}$ of an inch). The longest fibers are found in the wood of *Q. coccinea*, while the shortest occur in *Q. arizonica* and *Q. rubra*.

The ends of some wood fibers are flattened and sometimes even forked and with a saw edge (fig. 8b, *a* and *b*). Fibers usually run parallel to one another, but there may be seen in some of the western species a decided interweaving with one another, which produces "cross-grained" wood, difficult to split.

WOOD-PARENCHYMA FIBERS.

The individual cells of wood-parenchyma fibers resemble the pith-ray cells, but they are grouped in vertical rows instead of horizontal rows (figs. 9 and 10). They predominate in the more porous parts

[1] All dimensions of wood elements given in this work are averages not only of a great many different measurements of elements from a large number of samples, but also of elements from different parts of the same specimens. It is advisable, therefore, in attempting to trace down a piece of oak wood carefully to examine slides made from different parts of a specimen.

of the annual rings of growth and often closely surround the vessels and tracheids. In the dense late wood, wood-parenchyma fibers form conspicuous, tangentially arranged bands between irregular,

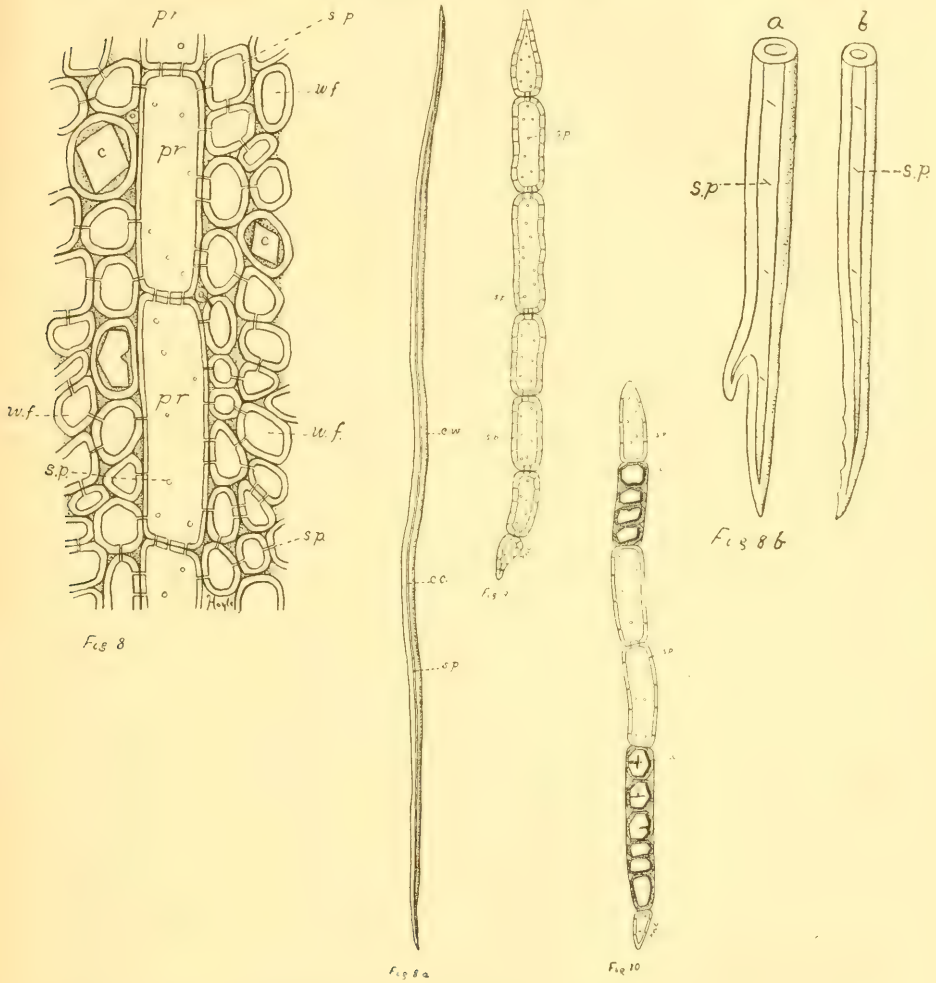

FIG. 8.—Transverse section of wood fibers; *p. r. c.*, pith ray cell; *c.*, crystal of calcium oxalate; *w. f.*, wood fibers; *s. p.*, simple pit. Magnified about 175 diameters.

FIG. 8a.—Wood fiber showing thick walls (*c. w.*), and a small cavity (*c. c.*); *s. p.*, simple pit. Magnified about 150 diameters.

FIG. 8b.—*a*, Wood fiber forked at one end; *b*, wood fiber with a saw-toothed edge at one end; *s. p.*, oblique simple pits. Magnified about 100 diameters.

FIG. 9.—Wood-parenchyma fiber showing individual cells (*c.*); *s. p.*, simple pits. Magnified about 125 diameters.

FIG. 10.—Crystalline masses (idioblasts) completely filling the individual cell cavities; *c*, crystals of calcium oxalate; *s. p.*, simple pits. Magnified about 125 diameters.

compact, radial rows of thick-walled wood fibers. On a perfectly smooth transverse section of oak wood, having well-defined late wood, these bands of wood-parenchyma fibers can be detected with the

unaided eye (fig. 15, *w. p. f.*). When greatly interrupted by wood fibers, the wood-parenchyma bands become indistinct and can be distinguished only by means of a microscope.

In late wood these elements are usually round in transverse section, but in early wood, where unequal pressure is exerted upon them by the rapid growth of vessels, they are flattened and their usual shape and arrangement are often greatly disturbed. The size, shape, and markings of wood-parenchyma fibers in late wood of different oaks vary but little. The pits are chiefly simple (fig. 9, *s. p.*), though occasionally wood-parenchyma cells are found that have bordered pits, as in the case of some evergreen oaks. The abundance, arrangement, and the particular relation these elements bear to one another are, however, important in distinguishing the wood of the different species of oaks.

Wood-parenchyma cells usually contain starch, and also a certain quantity of tannin, but these facts are of little value in identifying the different oaks, since the amount and nature of cell contents depend greatly upon the age of the tree, the time of the year the tree was cut, and the part of the tree from which the wood was taken.

Crystals of calcium oxalate (fig. 10, *c.*) are found in all parenchymatous tissue of all species of oaks. They are developed singly in the cells and belong to the tetragonal crystal system. These crystals are only slightly soluble even in the strongest acids and are very clearly visible under the high power of the microscope both in transverse and longitudinal sections. In pith-ray cells they are often found in rows of from 3 to 6, while in wood-parenchyma fibers they occur in much longer rows, particularly in the early wood, and are technically known as idioblasts (fig. 10). In such cases the whole cell becomes merely a repository for the crystal. Such crystals are especially frequent in the wood of *Quercus arizonica*, *Q. californica*, *Q. douglasii*, *Q. emoryi*, *Q. gambelii*, *Q. garryana*, *Q. lobata*, *Q. lyrata*, *Q. reticulata*, *Q. texana*, and *Q. virginiana*. Individual samples of other oaks are often found, however, that contain as many crystals as those just named. A careful investigation has shown that the woods of evergreen oaks, and especially those of the Rocky Mountain and Pacific coast regions, contain more crystals than those of the eastern deciduous oaks in general.

PITH-RAY CELLS.

Pith-ray cells have already been briefly described in connection with pith rays. They occur in from one to many rows closely packed together, and individually are arranged end to end with their long axes in a radial direction. In a transverse section these radial rows of parenchyma cells can be seen as narrow but more or less distinct

lines; the larger ones (fig. 3, *p. p. r.*) extending from the pith to the periphery of the stem. The width and height (tangential section) of these rays are entirely dependent upon the age of the tree and upon the distance from the pith or periphery of the stem. In a tangential section the small pith rays are seen in vertical rows of a single cell in width, and from a few to 20 or more cells in height (fig. 3, *s. p. r.*). Where these cells are in contact with one another or with wood-parenchyma fibers the pits are simple (fig. 8, *s. p.* in *p. r.*), but if they lie next to vessels or tracheids the portion of the converging pits in vessel walls is bordered, and that of the ray cells is simple.

STRUCTURAL CHARACTERS USED FOR IDENTIFICATION.

The technical generic name of oak, *Quercus*, is derived from the Celtic words *quer*, meaning "fine," and *cuez*, "tree," in reference to its highly esteemed qualities. The genus *Quercus* belongs to the family *Fagaceæ*, which contains three other genera, *Fagus*, *Castanea*, and *Castanopsis*, native to the United States. The oaks are trees and shrubs distributed widely over the northern hemisphere and in parts of Java and South America. The different species vary greatly in the form and character of their leaves, fruit, bark, and general appearance, but there are no such marked constant characters as these present in the woods of oaks by means of which they can be readily distinguished. There is much variation in the appearance of the wood of the different oaks, but the woods of different trees of any particular species may also vary so remarkably in appearance, depending upon the conditions under which the trees grew, that it often requires very careful study to identify them.

The woods of the oaks described in this work are classified according to differences in the form and arrangement of the large and small vessels (pores), wood fibers, and wood-parenchyma fibers, also according to the width and outline of the annual rings of growth, and by a comparison of the early and late wood composing each ring. Microscopic characters have been resorted to only when the gross characters are insufficient for identification. A number of the evergreen oaks, native to high, dry plains of the Southwest, have hard wood, and show exceedingly narrow layers of growth and very wide pith rays. A few of our oaks have a very wide natural range of growth, which accounts in a great measure for the variability in the character of their woods. Bur oak, for instance, ranges from Nova Scotia westward to Manitoba and southwestward to Texas. Within this range it occurs both in the form of chaparral and as a large tree, and the character of the wood varies greatly with the different situations to which it has become adapted (figs. 23 and 24, p. 34).

ANALYTICAL KEY FOR THE IDENTIFICATION OF IMPORTANT NORTH AMERICAN OAKS, BASED ON CHARACTERS OF THE SECONDARY WOOD.[1]

A. Marked distinction between early and late wood.

1. Pores abruptly diminishing in size from early to late wood; large pores contain considerable tyloses.

WHITE AND WILLOW OAKS.

Pores in early wood arranged mostly in 1 tangential row or rarely in 2 distinct rows; pores in late wood half the size of those in early wood, few and scattered.....1. *Quercus laurifolia* (p. 24).

Pores in early wood arranged in 1 to 3 tangential rows; pores in late wood less than half the size of those in early wood.

Pores in late wood 0.05[2] millimeter or less in diameter and arranged irregularly or in single or double radial rows.

Pores in late wood mostly forming single radial rows; tangential bands of wood-parenchyma fibers conspicuous.....2. *Quercus gambelii* (p. 25).

Pores in late wood mostly forming double radial rows; tangential bands of wood-parenchyma fibers less conspicuous, except in 5.

Radial rows of small pores surrounded by wood-parenchyma fibers; these rows becoming wider near the periphery of the annual ring.
3. *Quercus garryana* (p. 26).

Walls of pores in early wood thicker than those in the late wood. Crystals of calcium oxalate rare.....4. *Quercus lobata* (p. 26).

Walls of pores in early wood thinner than those in the late wood. Crystals of calcium oxalate very numerous.

Pores in early wood vary from 0.05 to 0.2 millimeter in diameter; tangential bands of wood-parenchyma fibers very wide.
5. *Quercus reticulata* (p. 28).

Pores in early wood vary from 0.2 to 0.3 millimeter in diameter; tangential bands of wood-parenchyma fibers very inconspicuous.
6. *Quercus arizonica* (p. 29).

Pores in late wood more than 1 millimeter in diameter and arranged chiefly in single radial rows.

Radial rows of pores extending to periphery of annual rings of growth.

Pores in early wood round and from 0.15 to 0.25 millimeter in diameter.
7. *Quercus minor* (p. 29).

Pores in early wood chiefly elliptical and 0.2 to 0.3 millimeter in diameter.
8. *Quercus platanoides* (p. 30).

Radial rows of pores rarely extending to periphery of annual rings of growth.
9. *Quercus emoryi* (p. 31).

Pores in late wood very variable and arranged chiefly in double, radial rows.

Pores uniformly large and rows invariably extending to the periphery of annual rings of growth.....10. *Quercus californica* (p. 32).

Pores very irregular in size and radial rows rarely extending to the periphery of annual rings of growth.

[1] Sapwood and heartwood, the strictly woody parts of a tree stem, are collectively known as secondary wood, a technical name given to mature wood because its formation follows in the order of development the growth of tissue known as primary wood, which is intermediate in character between the purely parenchymatous tissue of pith and fully matured wood. The general order of growth in a tree stem is therefore, first, the production of the purely parenchymatous tissue of pith; second, the formation of primary wood; and third, the laying on of secondary wood. Following the production of pith and primary wood comes the formation of the so-called "cambium ring," a generative layer of thin-walled cells, which develops secondary wood on its inner side and bark on its outer side.

[2] See footnote 1, p. 15.

Wood-parenchyma fibers in late wood arranged chiefly in conspicuous, double, tangential bands. Tyloses very abundant.

Large pith rays about 4 millimeters apart.....11. *Quercus alba* (p. 33).

Large pith rays about 6 millimeters apart.

12. *Quercus macrocarpa* (p. 34).

Wood-parenchyma fibers in late wood scattered rather irregularly, occasionally in short, parallel, inconspicuous, tangential bands.

Pores in early wood arranged chiefly in one row, with broad, conspicuous radial rows of smaller pores.

Pores in early wood round or oval.....13. *Quercus breviloba* (p. 35).

Pores in early wood strongly elliptical.....14. *Quercus phellos* (p. 35).

Pores in early wood arranged chiefly in 2 to 3 rows and pores in late wood larger than in 13 and 14.

Radial rows of pores in late wood unusually wide; heartwood dark brown with lighter-colored sapwood....15. *Quercus lyrata* (p. 37).

Radial rows of pores in late wood usually narrower; heartwood light brown, with darker-colored sapwood..16. *Quercus michauxii* (p. 37).

Pores in early wood arranged in 3 to 5 rows.

Walls of pores in late wood thin; radial rows of small pores become wider toward periphery of annual rings of growth...17. *Quercus prinus* (p. 38).

Walls of pores in late wood thick; radial rows of small pores become narrower toward the periphery of the annual rings of growth.

Pores in late wood chiefly in single radial rows.

18. *Quercus acuminata* (p. 39).

Pores in late wood chiefly in double radial rows.

19. *Quercus imbricaria* (p. 41).

2. Pores gradually diminishing in size from early to late wood; large pores contain very little tyloses.

BLACK OAKS AND RED OAKS.

Pores in early wood arranged chiefly in 1 to 3 rows.

Radial rows of small pores usually numerous, double, and somewhat irregular; tangential bands of wood-parenchyma fibers very numerous.

20. *Quercus nigra* (p. 41).

Radial rows of small pores usually single and parallel; tangential bands of wood-parenchyma fibers few and inconspicuous.

Pores in early wood round; wood light brown and strongly tinged with orange; a tree seldom more than 4 decimeters in diameter near the base.

21. *Quercus catesbæi* (p. 42).

Pores in early wood elliptical or oval; wood light brown and faintly tinged with red; a tree often 6 to 8 decimeters in diameter near the base.

22. *Quercus digitata* (p. 43).

Pores in early wood arranged chiefly in 3 to 5 rows.

Wood-parenchyma fibers in late wood arranged in conspicuous, tangential bands more than one cell wide.

Pores in early wood very numerous and from 0.2 to 0.4 millimeter in diameter.

Pores filled with tyloses.....23. *Quercus marilandica* (p. 44).

Pores with very little tyloses.....24. *Quercus coccinea* (p. 45).

Pores in early wood less numerous and from 0.15 to 0.25 millimeter in diameter.

Pores in late wood 0.05 millimeter in diameter.

25. *Quercus brevifolia* (p. 46).

Pores in late wood 0.025 millimeter in diameter.

26. *Quercus palustris* (p. 46).

Wood-parenchyma fibers in late wood scattered irregularly among the wood fibers, or sometimes arranged in much interrupted, inconspicuous, tangential bands one cell wide.

Wood-parenchyma fibers very abundant in early wood; crystals of calcium oxalate numerous in pith ray cells.....27. *Quercus texana* (p. 48).

Wood-parenchyma fibers arranged in two or more double, concentric bands around the pores in early wood; crystals of calcium oxalate in pith ray cells very rare .....28. *Quercus velutina* (p. 48).

Wood-parenchyma fibers grouped irregularly around pores in early wood; crystals of calcium oxalate very rare.....29. *Quercus rubra* (p. 49).

B. Little distinction between early and late wood.

EVERGREEN OAKS, EXCEPT NO. 33.

1. Pores chiefly arranged in distinct radial rows.

Radial rows of pores in late wood usually single.

Tangential bands of wood-parenchyma fibers distinct.

30. *Quercus agrifolia* (p. 51).

Tangential bands of wood-parenchyma fibers rather indistinct.

31. *Quercus wislizeni* (p. 51).

Radial rows of pores in late wood usually double.

Tangential bands of wood-parenchyma fibers very short and confined to the outer portion of the late wood; in early wood these elements scattered.

32. *Quercus chrysolepis* (p. 53).

2. Pores rather uniformly distributed throughout the annual layers of growth.

Pores in early wood twice the size of those in late wood; annual rings of growth very narrow; heartwood dark or nearly black...33. *Quercus douglasii* (p. 53).

Pores in early and late wood nearly uniform in size; annual rings of growth wider; wood very light brown .....34. *Quercus densiflora* (p. 54).

Pores few, only slightly diminishing, but uniformly distributed across the annual rings of growth.....35. *Quercus virginiana* (p. 55).

CHARACTERISTICS OF THE DIFFERENT OAK WOODS.

1. Laurel Oak (*Quercus laurifolia* Michaux). (Fig. 11.)

Heartwood dark brown tinged with red; sapwood thick and somewhat lighter colored. Wood hard, heavy, strong, rather coarse-grained, and not very durable in contact with the soil. Rate of growth rather slow, requiring on an average from 10 to 12 years for the tree to increase 1 inch in diameter.

Vessels (fig. 11, *v.*) in early wood (*e. w.*) 1 or rarely 2 rows deep, round and approximately 0.25[1] millimeter in diameter, diminishing abruptly in late wood (*l. w.*) to about 0.12 millimeter. Small vessels in radial rows extending to the periphery of the annual ring of growth. *Wood fibers* (*w. f.*) very numerous both in the early and late wood, averaging 1.34 millimeters long and approximately 0.021 millimeter wide. Cell walls thick and the cavities rather small. *Wood-parenchyma fibers* uniformly distributed throughout the entire annual ring of growth. In the late wood they are arranged in single, irregular, indistinct tangential bands. *Pith rays:* Large pith rays

[1] See footnote 1, p. 15.

(*l. p. r.*) from 25 to 40 cells wide and from three to four times as high and from 2 to 3 millimeters apart; small pith rays (*s. p. r.*) rarely more than 1 cell wide and from a few to 15 cells high.

The wood of laurel oak resembles that of live oak (*Q. virginiana*), but is easily distinguished by its less prominent pith rays and more distinct annual rings of growth.

2. Gambel Oak (*Quercus gambelii* Nuttall). (Fig. 12.)

Heartwood dark brown tinged with red; sapwood rather thin and much lighter colored. Wood hard, heavy, strong, close-grained,

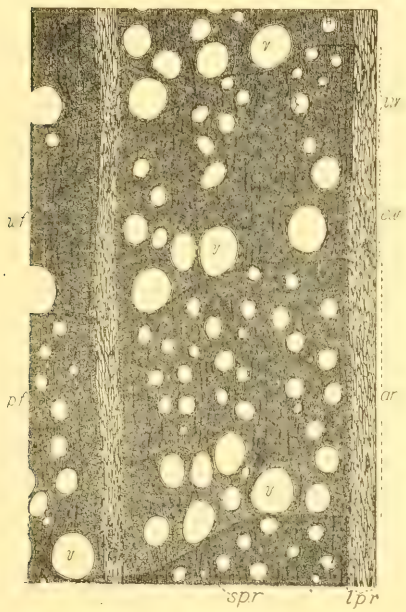

FIG. 11.

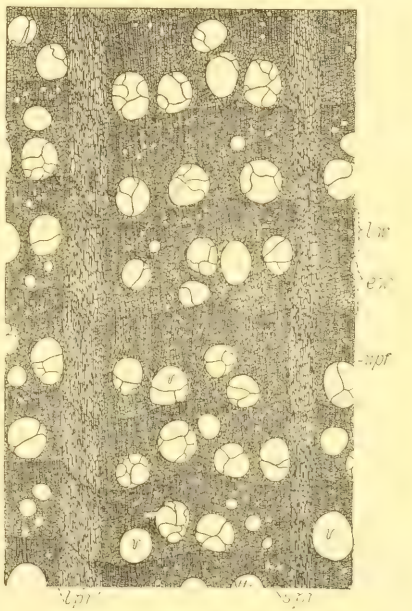

FIG. 12.

FIG. 11.—Laurel oak (*Quercus laurifolia*). Transverse section through two entire annual rings of growth; *a. r.*, annual ring; *e. w.*, early wood; *l. w.*, late wood; *l. p. r.*, large pith ray; *s. p. r.*, small pith ray; *v.*, vessel; *w. f.*, wood fiber; *w. p. f.*, wood-parenchyma fiber. Magnified 20 diameters.

FIG. 12.—Gambel oak (*Quercus gambelii*). Transverse section through six entire annual rings of growth: *e. w.*, early wood; *l. w.*, late wood; *l. p. r.*, large pith ray; *s. p. r.*, small pith ray; *v.*, vessel; *w. f.*, wood fiber; *w. p. f.*, wood-parenchyma fiber. Magnified 20 diameters.

and fairly durable in contact with the soil. Rate of growth exceedingly slow, requiring on an average from 15 to 20 years to grow 1 inch in diameter.

Vessels (fig. 12, *v.*) seldom more than 2 rows deep, round or occasionally in wide annual rings of growth elliptical or oval, and approximately from 0.1 to 0.25 millimeter in diameter. Vessel walls in early wood thicker than those in late wood. Small vessels in late wood abruptly smaller, seldom over 0.025 millimeter, forming from 1 to 3 single, or rarely double, irregular, radial rows extending across the entire width of the annual ring of growth. *Wood fibers* (*w. f.*) numerous in early wood, averaging 1.16 millimeters long and 0.018 milli-

meter wide. Walls exceedingly thick and cavities small. *Wood-parenchyma fibers* (*w. p. f.*) chiefly surround large and small vessels. In outer portion of late wood these cells are arranged in tangential bands from 2 to 4 cells wide and near the early wood only 1 cell wide. Crystals of calcium oxalate very numerous. *Pith rays:* Large pith rays (*l. p. r.*) very conspicuous, from 35 to 45 cells wide and from three to five times as high and from 1.5 to 2.5 millimeters apart. Individual cells generally filled with dark-brown coloring matter consisting of starch, tannin, and crystals of calcium oxalate. The small pith rays (*s. p. r.*) only 1 cell wide and from 4 to 15 cells high.

The wood of gambel oak can be distinguished from that of the garry oak (*Q. garryana*), with which it may be confused, by its dark-brown color.

3. **Pacific Post Oak** (*Quercus garryana* Douglas). (Fig. 13.)

Heartwood light yellow and clearly distinguished from the thin and nearly white sapwood. Wood is hard, exceedingly tough, close-grained, and very durable. Rate of growth rather slow, requiring from 12 to 15 years to increase 1 inch in diameter.

Vessels (fig. 13, *v.*) in early wood 2 or rarely 3 rows deep, oval, with an average radial diameter of 0.35 millimeter and tangential diameter of 0.25 millimeter. In late wood (*l. w.*) they abruptly diminish to a uniform size of about 0.05 millimeter in diameter, arranged in two wide radial rows surrounded by numerous concentric bands of wood-parenchyma fibers visible under the compound microscope. Walls of small vessels in late wood thinner than those in early wood. *Wood fibers* (*w. f.*) on an average 1.3 millimeters long and about 0.018 millimeter wide. Walls thick and cavities small, occurring in more or less isolated and compact groups between the radial rows of small vessels and tangential bands of wood-parenchyma fibers. *Wood-parenchyma fibers* (*w. p. f.*) very abundant in early wood; also forming concentric bands around the small vessels in the radial rows and from 3 to 5 narrow, conspicuous tangential bands in late wood. *Pith rays:* Large pith rays (*l. p. r.*) are about 300 cells wide and from four to five times as high and from 3 to 4 millimeters apart. Small pith rays (*s. p. r.*) are only a single cel wide and from a few to 20 cells high.

(See reference under Valley oak to possible confusion of this wood with others.)

4. **Valley Oak** (*Quercus lobata* Nees von Esenbeck). (Fig. 14.)

Heartwood light brown tinged with red; sapwood rather thin and much lighter colored. Wood hard, heavy, rather fine-grained, brittle, and durable in contact with the soil. Although individual trees of this species grow moderately fast, most samples show that from 12 to 18 years are required for a tree to grow 1 inch in diameter.

Vessels (fig. 14, *v.*) in early wood (*e. w.*) 1 to 2 rows deep, round, varying from 0.2 to 0.5 millimeter in diameter, and generally filled with tyloses (*t.*); in late wood (*l. w.*) they become abruptly smaller, averaging approximately 0.06 millimeter and are distributed uniformly across the late wood. *Wood fibers* (*w. f.*) average about 1.24 millimeters in length and are chiefly confined to late wood; early wood being almost wholly composed of large vessels and wood-parenchyma fibers. Cell walls thick with rather small cavities. *Wood-parenchyma fibers* (*w. p. f.*) abundant in early wood, surround-

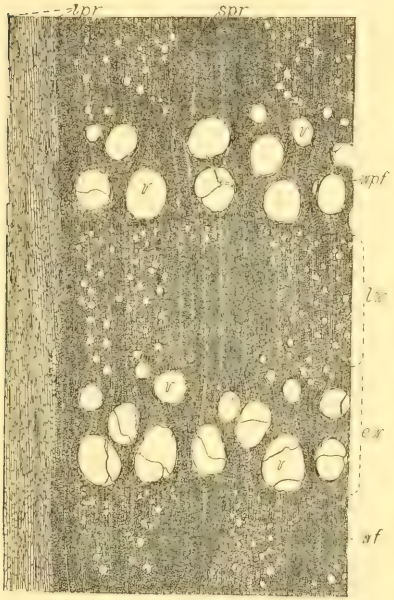

FIG. 13.

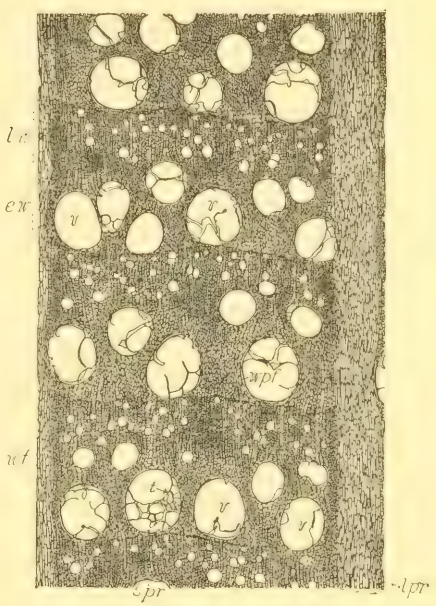

FIG. 14.

FIG. 13.—Pacific post oak (*Quercus garryana*). Transverse section through one entire annual ring of growth; *e. w.*, early wood; *l. w.*, late wood; *l. p. r.*, large pith ray; *s. p. r.*, small pith ray; *v.*, vessel; *w. f.*, wood fiber; *w. p. f.*, wood-parenchyma fiber. Magnified 20 diameters.

FIG. 14.—Valley oak (*Quercus lobata*). Transverse section through three entire annual rings of growth; *e. w.*, early wood; *l. w.*, late wood; *l. p. r.*, large pith ray; *s. p. r.*, small pith ray; *v.*, vessel; *w. f.*, wood fiber; *w. p. f.*, wood-parenchyma fiber; *t.*, tyloses. Magnified 20 diameters.

ing large pores; more sparingly found in late wood with an almost entire absence of tangential arrangement. Numerous calcium oxalate crystals present. *Pith rays:* Large pith rays (*l. p. r.*) are from 10 to 25 cells wide, and from two to six times as high and from 1 to 4 millimeters apart. Small pith rays (*s. p. r.*) inconspicuous and very irregular on account of the numerous pores which they avoid.

The wood of valley oak is distinguished from blue oak (*Q. douglasii*) by its lighter brown color, and from the similar garry oak (*Q. garryana*) by the latter's very much wider pith rays.

5. Netleaf Oak (*Quercus reticulata* Humboldt, Bonpland and Kunth). (Fig. 15.)

Heartwood dark brown and occasionally tinged with red; sapwood thick and much lighter colored. Wood hard, heavy, very close-grained and not very durable in contact with the soil. Very little contrast between early and late wood. Rate of growth very slow, requiring from 12 to 18 years to grow 1 inch in diameter.

Vessels (fig. 15, *v.*) in early wood (*e. w.*) from 1 to 3 interrupted rows deep, varying in diameter from 0.05 to 0.2 millimeter; those

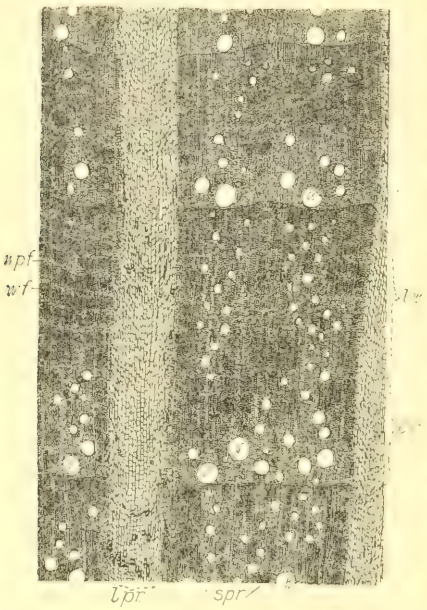

FIG. 15.

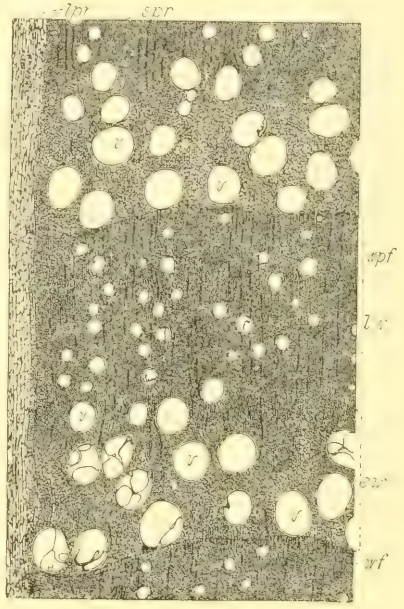

FIG. 16.

FIG. 15.—Netleaf oak (*Quercus reticulata*).—Transverse section through two entire annual rings of growth; *e. w.*, early wood; *l. w.*, late wood; *l. p. r.*, large pith ray; *s. p. r.*, small pith ray; *v.*, vessel; *w. f.*, wood fiber; *w. p. f.*, wood-parenchyma fiber. Magnified 20 diameters.

FIG. 16.—Arizona white oak (*Quercus arizonica*). Transverse section through one annual ring of growth *e. w.*, early wood; *l. w.*, late wood; *l. p. r.*, large pith ray; *s. p. r.*, small pith ray; *v.*, vessel; *w. f.*, wood fiber; *w. p. f.*, wood-parenchyma fiber. Magnified 20 diameters.

first formed often much smaller than many in the late wood (*l. w.*), which are arranged in single or double and irregular radial rows, and surrounded by numerous wood-parenchyma fibers. *Wood fibers* (*w. f.*) average 1.06 millimeters long, with very thick walls and small cavities; only sparingly found in early wood. *Wood-parenchyma fibers* (*w. p. f.*) very abundant in late wood, occurring in numerous broad tangential bands from 0.2 to 0.5 cell wide and extending from ray to ray as uninterrupted lines. Crystals of calcium oxalate very numerous. *Pith rays:* Large pith rays (*l. p. r.*) very numerous and from 20 to 40 cells wide and from three to five times as high. Crystals of calcium oxalate present. Small pith

rays (*s. p. r.*) only a single cell wide and from 4 to 20 cells high, rather inconspicuous

6. Arizona White Oak (*Quercus arizonica* Sargent). (Fig. 16.)

Heartwood dark brown or sometimes nearly black; sapwood thick and much lighter colored. Wood hard, very heavy, strong, close-grained, very durable in contact with the soil, and exceedingly variable in its general gross characters. Rate of growth rather slow, requiring from 15 to 18 years for the tree to grow 1 inch in diameter.

Vessels (fig. 16, *v.*) in early wood (*e. w.*) 1 to 2 rows deep, round and from 0.2 to 0.3 millimeter in diameter, becoming abruptly smaller in late wood (*l. w.*), where they are from one-fourth to one-third as large as those in early wood and of nearly uniform diameter. Walls of small vessels in late wood thicker than those of larger pores in early wood. Distribution of small pores rather irregular, though a slight resemblance to radial arrangement present in wood showing wide annual rings of growth. *Wood-fibers* (*w. f.*) form bulk of late wood, but are seldom present between larger pores in early wood. Walls rather thick and cavities small. Length varies from 0.71 to 1.42 millimeters with average width of 0.018 millimeter. *Wood-parenchyma fibers* (*w. p. f.*) almost entirely confined to early wood, forming the bulk of the elements which compose the inner half of annual rings of growth. Almost entire absence of tangential arrangement in late wood; traces of such bands present in outer portion. *Pith rays:* Large pith rays (*l. p. r.*) very numerous, from 20 to 30 cells wide, from three to four times as high and from 1.5 to 3.5 millimeters apart; the cells contain numerous crystals of calcium oxalate. Small pith rays (*s. p. r.*) inconspicuous, only a single cell wide and from 3 to 15 cells high.

7. Post Oak (*Quercus minor* (Marsh) Sargent). (Fig. 17.)

Heartwood light brown or sometimes tinged with red; sapwood thick and lighter colored. Wood very heavy, hard, close-grained, and in durability compares with that of white oak. Rate of growth rather slow, requiring approximately 16 years to grow 1 inch in diameter.

Vessels (fig. 17, *v.*) in early wood (*e. w.*) generally 2 rows deep, round, and about 0.2 millimeter in diameter. In late wood (*l. w.*) nearly uniform in size, approximately one-third as large as those in early wood and arranged in nearly regular radial rows of from 3 to 5 between the large pith rays. *Wood fibers* (*w. f.*) compose major part of annual rings of growth. Walls very thick, rendering the wood exceedingly hard and heavy. Length varies from 0.83 to 1.25 millimeters with an average of 0.98 millimeter. *Wood-parenchyma fibers* (*w. p. f.*) occur sparingly in early wood. From 4 to 10 inconspicuous tangential bands of average width in late wood. *Pith rays:* Large pith rays (*l. p. r.*) are about 25 cells wide and about four times

as high and 3 millimeters apart. Approximately 30 small rays (*s. p. r.*) only a single cell wide occur between the large rays.

Post oak resembles white oak (*Q. alba*), but is distinguished from it by more numerous and conspicuous pith rays and smaller pores in the early wood.

8. Swamp White Oak (*Quercus platanoides* (Lambert) Sudworth). (Figs. 18 and 19.)

Heartwood light brown, sometimes slightly tinged with red; sapwood rather thin and somewhat lighter colored. Wood very hard, heavy, strong and equally as durable in contact with the soil as white oak. Rate of growth moderately fast, requiring on an average about 9 years to grow 1 inch in diameter.

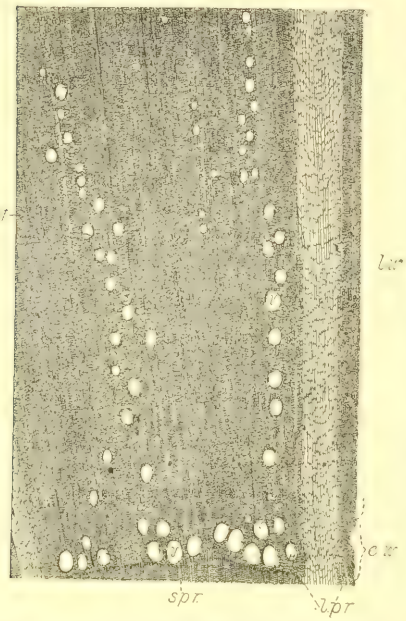

FIG. 17.—Post oak (*Quercus minor*). Transverse section through one entire annual ring of growth; *e. w.*, early wood; *l. w.*, late wood; *l. p. r.*, large pith ray; *s. p. r.*, small pith ray; *v.*, vessel; *w. f.*, wood fiber. Magnified 20 diameters.

Vessels (fig. 19, *v.*) in early wood (*e. w.*) from 1 to 3 rows deep; the inner row usually large and elliptical, and the succeeding rows usually very much smaller and round. Large vessels from 0.2 to 0.3 millimeter in diameter. In late wood (*l. w.*) they become abruptly smaller and arranged in more or less narrow, radial rows, of which there are frequently from ten to twelve between the large pith rays (*l. p. r.*). Occasionally these radial rows originate in the middle of late wood and extend to the outer part of annual ring of growth. They average about 0.04 millimeter in diameter. *Wood fibers* (*w. f.*) approximately 1.04 millimeters long with thick walls and relatively small cavities. *Wood-parenchyma fibers* (*w. p. f.*) chiefly confined to the early wood, but border small vessels in late wood. They are arranged in numerous, inconspicuous, tangential bands in late wood. *Pith rays:* Large pith rays (*l. p. r.*) are from 15 to 25 cells wide, from three to four times as high, and from 8 to 10 millimeters apart. Small rays (*s. p. r.*) exceedingly numerous but seldom more than 1 cell wide.

Swamp white oak superficially resembles white oak (*Q. alba*), from which it is distinguished by its very light-brown color, contrasting more or less sharply with the reddish-brown color of white oak wood.

9. Emory Oak (*Quercus emoryi* Torrey). (Fig. 20.)

Heartwood dark brown or sometimes nearly black; sapwood rather thick and light brown, tinged with red. Wood hard, heavy, strong, close-grained, and not durable in contact with the soil. Wood of old or slow-growing trees very brittle. Rate of growth very slow, requiring from 12 to 15 years to grow 1 inch in diameter.

Vessels (fig. 20, *v.*) in early wood (*e. w.*) are from 2 to 4 rows deep and vary from 0.15 to 0.35 millimeter in diameter, gradually diminish-

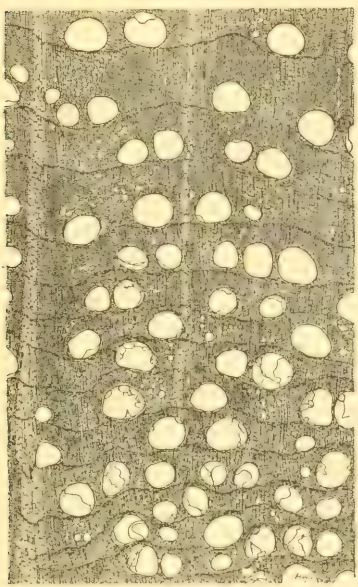

FIG. 18.

FIG. 19.

FIG. 18.—Swamp white oak (*Quercus platanoides*). Transverse section through 13 entire annual rings of growth. Magnified 20 diameters.

FIG. 19.—Swamp white oak (*Quercus platanoides*). Transverse section through one entire ring of annual growth; *e. w.*, early wood; *l. w.*, late wood; *l. p. r.*, large pith ray; *s. p. r.*, small pith ray; *v.*, vessel; *w. f.*, wood fiber; *w. p. f.*, wood-parenchyma fiber. Magnified 20 diameters.

ing in size in late wood (*l. w.*), where they are 0.1 millimeter or less in diameter. Small vessels arranged in regular single or rarely double radial rows extending to the outer part of the annual ring of growth. Usually two, though occasionally 1 and rarely 3 or 4 radial rows of small vessels between the large pith rays. Walls of small vessels thicker than those of large ones in early wood. *Wood fibers* (*w. f.*) on an average 1.12 millimeters long and about 0.02 millimeter wide. Walls thick and the cavities very small, especially near the periphery of the annual rings of growth. *Wood-parenchyma fibers* (*w. p. f.*) very abundant in early wood and along the radial rows of small pores. Numerous single or double tangential bands in late wood. *Pith rays:* Large pith rays (*l. p. r.*) are very numerous and vary from 10 to 25

cells wide, from three to four times as high, and from 1.5 to 2.5 millimeters apart; conspicuous in transverse sections. Small pith rays (*s. p. r.*) conspicuous and cells unusually large compared to those of other oaks. Crystals of calcium oxalate usually confined to cells of large pith rays and to wood-parenchyma fibers.

10. California Black Oak (*Quercus californica* (Torrey) Cooper). (Fig. 21.)

Heartwood bright red or tinged with yellow; sapwood thin, lighter colored and easily distinguished from heartwood. Wood hard,

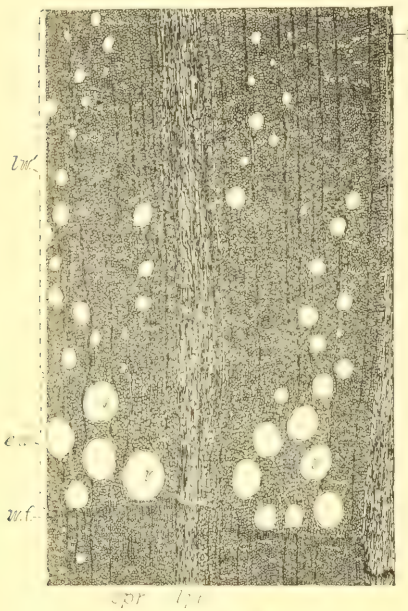

FIG. 20.

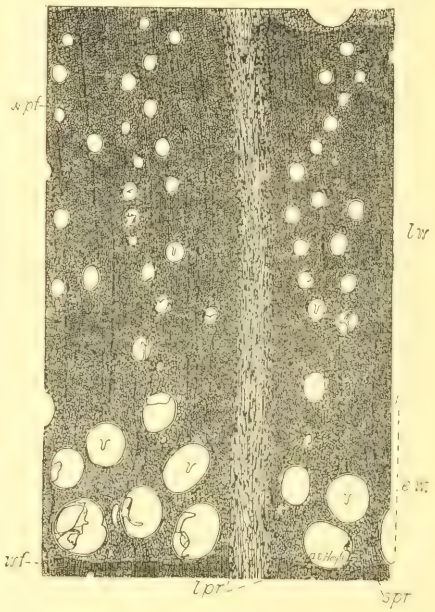

FIG. 21.

FIG. 20.—Emory oak (*Quercus emoryi*). Transverse section through parts of two annual rings of growth; *e. w.*, early wood; *l. w.*, late wood; *l. p. r.*, large pith ray; *s. p. r.*, small pith ray; *v.*, vessel; *w. f.*, wood fiber; *w. p. f.*, wood-parenchyma fiber. Magnified 20 diameters.

FIG. 21.—California black oak (*Quercus californica*). Transverse section through one entire annual ring of growth; *e. w.*, early wood; *l. w.*, late wood; *l. p. r.*, large pith ray; *s. p. r.*, small pith ray; *v.*, vessel; *w. f.*, wood fiber; *w. p. f.*, wood-parenchyma fiber. Magnified 20 diameters.

heavy, strong, though brittle, rather close-grained and not durable in contact with the soil. The tree requires from 12 to 15 years to grow 1 inch in diameter.

Vessels (fig. 21, *v.*) in early wood (*e. w.*) from 3 to 5 rows in moderately fast-growing trees, occupying about one-fifth of the width of the annual ring of growth; the vessels are from 0.2 to 0.45 millimeter in diameter. Small vessels in late wood (*l. w.*) occur in single or double and rather irregular radial rows extending to the outer edge of the annual ring, usually uniform in size and measuring about 0.1 millimeter in diameter. *Wood fibers* (*w. f.*) form the bulk of late wood

and are approximately 1.21 millimeters long and about 0.022 millimeter wide. *Wood-parenchyma fibers* (*w. p. f.*) conspicuously arranged in irregular tangential bands from 2 to 6 cells wide. In early wood they are filled either with starch, tannin, or crystals of calcium oxalate. *Pith rays:* Large pith rays (*l. p. r.*) from 10 to 30 cells wide, from three to five times as high, and from 2 to 3 millimeters apart. Small pith rays (*s. p. r.*) very clearly defined in transverse sections.

11. White Oak (*Quercus alba* Linnæus). (Fig. 22.)

Heartwood reddish brown; sapwood narrow and light colored. Wood very hard, heavy, strong, close-grained, and very durable in contact with the soil. Rate of growth moderately fast, requiring about 10 years to grow 1 inch in diameter.

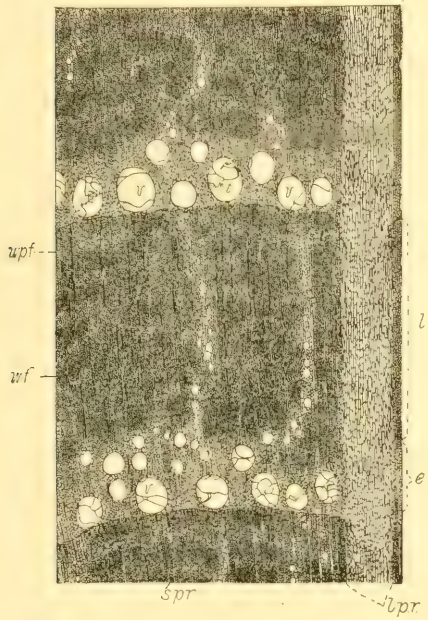

FIG. 22.—White oak (*Quercus alba*). Transverse section through one entire annual ring of growth; *e. w.*, early wood; *l. w.*, late wood; *l. p. r.*, large pith ray; *s. p. r.*, small pith ray; *v.* vessel; *w. f.*, wood fiber; *w. p. f.*, wood-parenchyma fiber; *t.*, tyloses. Magnified 20 diameters.

Vessels (fig. 22, *v.*) in early wood (*e. w.*) round, from 0.3 to 0.5 millimeter in diameter, and 1 row, or rarely 2 or more rows, deep. In late wood (*l. w.*) vessels abruptly diminish in diameter to approximately one-sixth of that in early wood, where they vary but little in size and outline. Practically all the large vessels are filled with tyloses (*t.*). *Wood fibers* (*w. f.*) from 1 to 1.63 millimeters long and about 0.018 millimeter in diameter, forming the bulk of late wood. They have very thick walls and consequently rather small cavities. *Wood-parenchyma fibers* (*w. p. f.*) scattered irregularly throughout the early wood. In late wood they occur in distinct single or double irregular, tangential bands, varying from a few to many, depending upon the width of the annual rings of growth. *Pith rays:* Large pith rays (*l. p. r.*) are from 10 to 40 cells wide, and from three to five times as high, and approximately 0.4 millimeter apart. Small pith rays (*s. p. r.*) usually 1 cell wide, though some rays are from 2 to 3 cells wide and from a few to 20 cells high.

The wood of white oak is readily distinguished from that of red oak by the fact that the pores in the late wood diminish abruptly in

the former, while in the latter they diminish gradually in size. Another character helpful in separating these two species is the presence of tyloses within the pores of white oak and their absence in those of the red oak.

White oak wood may be confused with the wood of bur oak (*Q. macrocarpa*), swamp white oak (*Q. platanoides*), post oak (*Q. minor*), chestnut oak (*Q. prinus*), cow oak (*Q. michauxii*), chinquapin oak

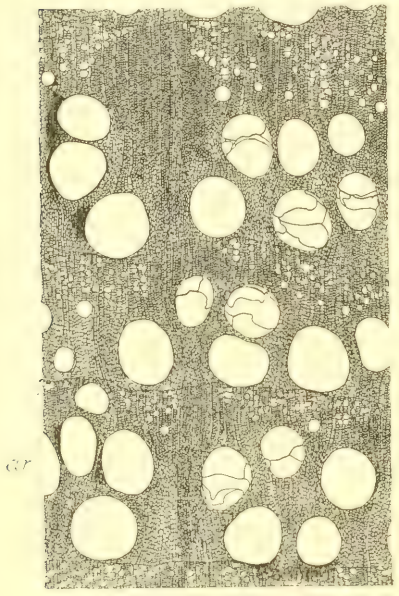

Fig. 23.

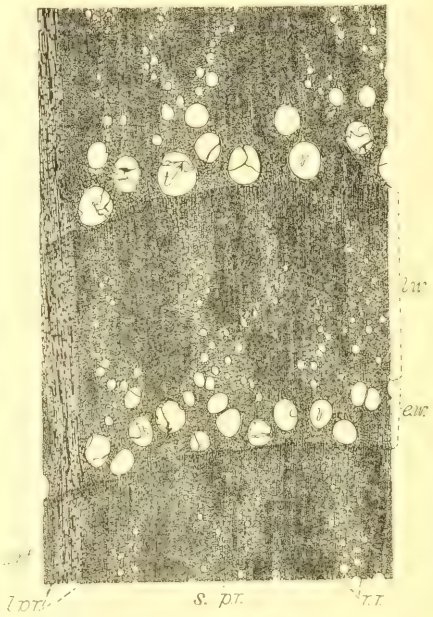

Fig. 24.

Fig. 23.—Bur oak (*Quercus macrocarpa*). Transverse section through three entire annual rings of growth; *a. r.*, annual ring. Magnified 20 diameters.

Fig. 24.—Bur oak (*Quercus macrocarpa*). Transverse section through one entire annual ring of growth; *e. w.*, early wood; *l. w.*, late wood; *l. p. r.*, large pith ray; *s. p. r.*, small pith ray; *v.*, vessel; *r. r.*, radial row; *w. f.*, wood fiber; *w. p. f.*, wood-parenchyma fiber; *t.*, tyloses. Magnified 20 diameters.

(*Q. acuminata*), and overcup oak (*Q. lyrata*). See special distinctions under each.

12. Bur Oak (*Quercus macrocarpa* Michaux). (Figs. 23 and 24.)

Heartwood dark, rich brown in color; sapwood thin and much lighter in color. Wood hard, heavy, very strong and tough, close-grained, and not liable to warp or check. Lumber never distinguished from white oak (*Quercus alba*) on the market. The most valuable timber of the American oaks.

This oak has the power to adapt itself to great variation of soil and climatic conditions, which enables it to live from Maine to Manitoba and southwest to Texas. The character of the wood produced under favorable conditions varies considerably from that produced near the limits of its botanical distribution. Illustrations of

transverse sections of different samples of wood are here shown. Figure 24 shows a transverse section of wood collected in southern Indiana, where the bur oak attains its largest size and greatest value; the wood from which figure 23 was made was collected in northwestern Minnesota, where this species approaches the chaparral form and consequently has very narrow annual rings of growth (fig. 23, *a. r.*).

Bur oak may often be distinguished from white oak by its wider radial rows of small vessels (fig. 24, *r. r.*) in late wood (*l. w.*). In white oak small pores often form a single narrow and rather regular row between the large pith rays (*l. p. r.*); while in the bur oak they are scattered in several rather wide bands bordered by wood-parenchyma fibers (*w. p. f.*), which often renders the wood somewhat lighter than that of white oak. Tangential bands of wood-parenchyma fibers are more conspicuous in bur oak. The wood fibers (*w. f.*) average about 1.35 millimeters long and 0.021 millimeter in diameter. Large pith rays (*l. p. r.*) are about 6 millimeters apart.

13. Durand Oak (*Quercus breviloba* (Torrey) Sargent). (Fig. 25.)

Heartwood small and brown in color; sapwood thick and much lighter colored. Wood moderately hard, rather light, though brittle, and in general appearance resembles white oak; not durable in contact with the soil. Rate of growth very slow, especially near its limits of distribution, requiring approximately 15 years to grow 1 inch in diameter.

Vessels (fig. 25, *v.*) in early wood (*e. w.*) oval and generally only a single row deep; generally contain considerable tyloses (*t.*). Small vessels in late wood (*l. w.*) surrounded by wood-parenchyma fibers (*w. p. f.*); they diminish in size abruptly and form broad radial rows (*r. r.*) which widen or become branched as they approach the periphery of the annual ring of growth (*a. r.*). *Wood fibers* (*w. f.*) chiefly occur in groups scattered through the late wood. They are 1.23 millimeters long, which is only slightly shorter than those of white oak. Walls thick and cavities small. *Wood-parenchyma fibers* highly developed and largely confined to late wood, rendering the wood among the lightest of the eastern oaks. *Pith rays:* Large pith rays (*l. p. r.*) from 10 to 30 cells wide and from three to four times as high. Distance between the large rays varies exceedingly in different parts of the same specimens. They are more numerous in this species, however, than in white oak. Small pith rays (*s. p. r.*) numerous but inconspicuous, only a single cell wide and from a few to 20 or more cells high.

14. Willow Oak (*Quercus phellos* Linnæus). (Fig. 26.)

Heartwood reddish brown, sometimes tinged with yellow; sapwood thin and much lighter colored, though sometimes slightly tinged

with red. Wood moderately hard, heavy, strong, rather cross-grained, and moderately durable in contact with soil. Rate of growth usually rather slow, requiring from 10 to 15 years to grow 1 inch in diameter.

Vessels (fig. 26, *v.*) in early wood (*e. w.*) are elliptical or oval in outline, with an average radial diameter of from 0.25 to 0.4 millimeter and tangential diameter of from 0.2 to 0.3 millimeter. Usually

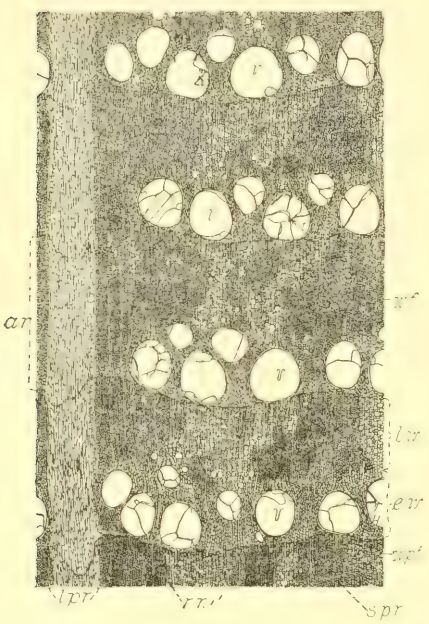

FIG. 25.

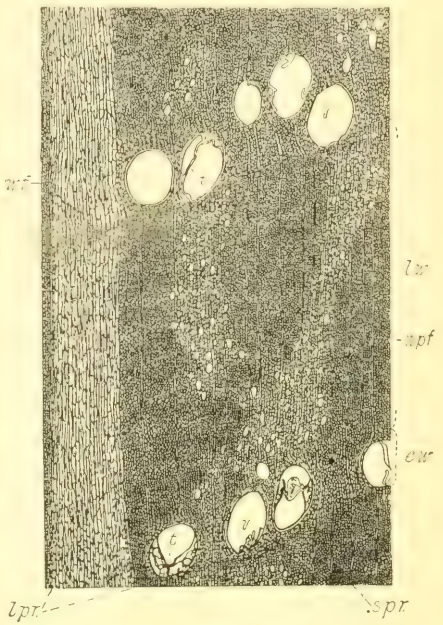

FIG. 26.

FIG. 25.—Durand oak (*Quercus breviloba*). Tranverse section through three entire annual rings of growth; *a. r.*, annual ring; *e. w.*, early wood; *l. w.*, late wood; *l. p. r.*, large pith ray; *s. p. r.*, small pith ray; *v.*, vessel; *r. r.*, radial row; *w. f.*, wood fiber; *w. p. f.*, wood-parenchyma fiber; *t.*, tyloses. Magnified 20 diameters.

FIG. 26.—Willow oak (*Quercus phellos*). Transverse section through one entire annual ring of growth; *e. w.*, early wood; *l. w.*, late wood; *l. p. r.*, large pith ray; *s. p. r.*, small pith ray; *v.*, vessel; *w. f.*, wood fiber; *w. p. f.*, wood-parenchyma fiber; *t.*, tyloses. Magnified 20 diameters.

only a single row of vessels within an annual ring of slow growing trees and chiefly filled with tyloses (*t.*); in fast growing trees usually from 2 to 3 rows, abruptly diminishing in size in late wood (*l. w.*). Small vessels often laterally compressed and irregular in outline and arranged in 2 or 3 rather conspicuous radial rows between the large pith rays. *Wood fibers* (*w. f.*) 1.52 millimeters long and 0.021 millimeter wide. They are seldom found to any great extent in early wood, but form the bulk of elements in late wood between the radial rows of small vessels and entirely surrounded by wood-parenchyma fibers. *Wood-parenchyma fibers* (*w. p. f.*) are confined chiefly to early wood and bordering the small vessels in late wood. The tangential bands of wood-parenchyma fibers, so common in most

oaks, occur very sparingly in the wood of this species. There are a few short bands or groups of these elements, but usually they can be distinguished only under the microscope. *Pith rays:* Large pith rays (*l. p. r.*) from 10 to 30 cells wide, and from two to four times as high, and from 2 to 3 millimeters apart. Small rays (*s. p. r.*) are, as a rule, only a single cell wide, and from a few to 20 cells high.

The wood of willow oak, frequently confused with that of shingle oak (*Q. imbricaria*), is distinguished by having less porous early wood than the latter, while the pores in the early wood of willow oak are usually elliptical, those in the shingle oak being round.

15. Overcup Oak (*Quercus lyrata* Walter). (Fig. 27.)

Heartwood dark brown and easily distinguished from the thick lighter-colored sapwood. Wood moderately hard, rather heavy, strong, and very durable in contact with soil. In its general appearance, physical characteristics, and rate of growth it is similar to white oak.

Vessels (fig. 27, *v.*) in early wood (*e. w.*), 2 to 3 rows deep; and, as well as the smaller pores in late wood (*l. w.*), are slightly compressed laterally. They are abruptly smaller in diameter in late wood, forming broad and often rather irregular, radial bands surrounded by conspicuous and thin-walled wood-parenchyma fibers (*r. r.*). *Wood fibers* (*w. f.*) are 1.32 millimeters long and 0.022 millimeter in diameter, and less numerous than those of white oak; their walls are usually somewhat thinner. *Wood-parenchyma fibers* (*w. p. f.*) arranged in clearly defined tangential bands in late wood. The number of these bands varies with the width of the annual rings of growth. *Pith rays:* Large pith rays (*l. p. r.*) are from 15 to 40 millimeters wide and from three to five times as high. Small rays (*s. p. r.*) are only a single cell wide and from a few to 20 or more cells high.

Overcup oak wood, sometimes confused with white oak (*Q. alba*), is readily distinguished from the latter by its larger and more numerous pores in the early wood.

16. Cow Oak (*Quercus michauxii* Nuttall). (Fig. 28.)

Heartwood light brown or somewhat tinged with red; sapwood thin and somewhat darker colored. Wood hard, heavy, tough, close-grained and durable in contact with soil. Under favorable conditions cow oak requires from 8 to 10 years to grow 1 inch in diameter. In the form of lumber it is seldom distinguished from white oak.

Vessels (fig. 28, *v.*) in early wood (*e. w.*) from 2 to 3 rows deep, and approximately 0.5 millimeter in radial and 0.4 millimeter in tangential diameter. In late wood (*l. w.*) small vessels arranged in 3 to 5 radial rows, which gradually widen or become branched near the periphery of annual rings of growth. *Wood fibers* (*w. f.*) are thick walled and on an average 1.54 millimeters long and 0.021 millimeter

wide. They form the bulk of the elements in late wood. *Wood-parenchyma fibers* (*w. p. f.*) are confined chiefly to early wood, but also surround the smaller vessels in late wood. Narrow, irregular, tangential bands of wood-parenchyma fibers occur in the outer part of late wood. *Pith rays:* Large pith rays (*l. p. r.*) are from 20 to 40 cells wide and from one to three times as high. Small rays (*s. p. r.*) are exceedingly numerous and are only one cell wide and from a few to 20 or more cells high.

Cow oak wood, which resembles white oak (*Q. alba*) more closely than that of any other species, is lighter colored and generally has

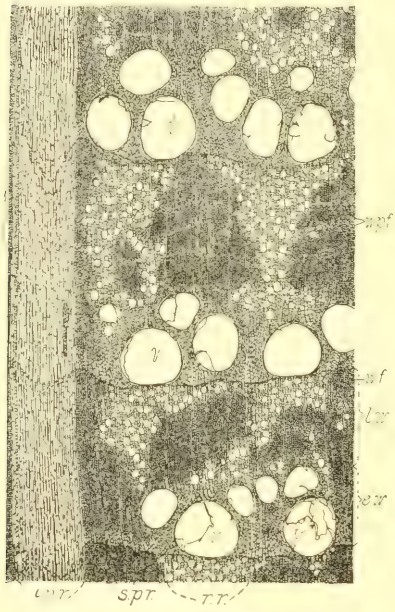

FIG. 27.

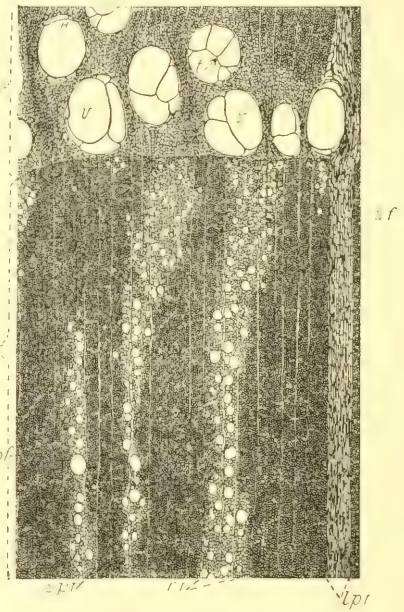

FIG. 28.

FIG. 27.—Overcup oak (*Quercus lyrata*). Transverse section through one entire annual ring of growth; *e. w.*, early wood; *l. w.*, late wood; *l. p. r.*, large pith ray; *s. p. r.*, small pith ray; *v.*, vessel; *r. r.*, radial row; *w. f.*, wood fiber; *w. p. f.*, wood-parenchyma fiber; *t.*, tyloses. Magnified 20 diameters.

FIG. 28.—Cow oak (*Quercus michauxii*) Transverse section through a portion of two annual rings of growth; *e. w.*, early wood; *l. w.*, late wood; *l. p. r.*, large pith ray; *s. p. r.*, small pith ray; *v.*, vessel; *r. r.*, radial row; *w. f.*, wood fiber; *w. p. f.*, wood-parenchyma fiber; *t.*, tyloses. Magnified 20 diameters.

less conspicuous tangential bands of wood-parenchyma fibers in the late wood than white oak.

17. Chestnut Oak (*Quercus prinus* Linnæus). (Fig. 29.)

Heartwood yellowish or reddish brown and sharply defined from the lighter and slightly reddish, narrow sapwood. Wood hard, heavy, strong, tough, moderately close-grained and durable in contact with soil. Rate of growth is low, requiring from 12 to 20 years for the tree to grow 1 inch in diameter.

Vessels (fig. 29, *v.*) round or elliptical in early wood (*e. w.*) and from 3 to 5 rows deep. Small vessels in late wood (*l. w.*) often polygonal

and sometimes so small that their diameters hardly exceed those of wood-parenchyma fibers. Radial rows (*r. r.*) of small vessels are wavy or slightly branched, and surrounded by numerous wood-parenchyma fibers which form narrow tangential bands (*w. p. f.*) in late wood. *Wood fibers* (*w. f.*) compose the bulk of late wood and are about 1.31 millimeters long and 0.020 millimeter wide, with thick walls and rather small cavities. *Wood-parenchyma fibers* (*w. p. f.*) are scattered in isolated groups in early wood. In late wood they occur in regular or branched and uninterrupted tangential bands which can be readily seen with the unaided eye. *Pith rays* exceedingly numerous and constitute about one-fifth of the cellular substance of the wood. Large pith rays (*l. p. r.*) are often 20 to 30 cells wide and from three to six times as high. Small pith rays (*s. p. r.*) only one cell wide and from 4 to 15 cells high, appearing as long, well-defined lines in transverse sections.

The wood of chestnut oak is sometimes mistaken for white oak (*Q. alba*), but it is distinguished from the latter by its more prominent pith rays and the lack of a faint reddish tinge present in the wood of white oak.

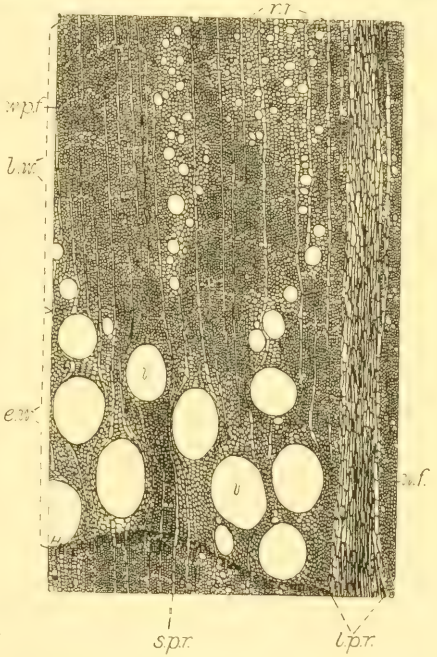

FIG. 29.—Chestnut oak (*Quercus prinus*). Transverse section through one entire annual ring of growth; *e. w.*, early wood; *l. w.*, late wood; *l. p. r.*, large pith ray; *s. p. r.*, small pith ray; *v.*, vessel; *r. r.*, radial row; *w. f.*, wood fiber; *w. p. f.*, wood-parenchyma fiber. Magnified 20 diameters.

18. Chinquapin Oak (*Quercus acuminata* (Michaux) Houba). (Figs. 30 and 31.)

Heartwood light brown or slightly tinged with red; sapwood thin and lighter colored. Wood hard, heavy, strong, and close-grained. Its durability and rate of growth similar to that of chestnut oak.

Vessels (fig. 30, *v.*) in early wood (*e. w.*) round or sometimes elliptical and from 0.15 to 0.35 millimeter in diameter; seldom forming continuous rows, but are generally arranged in groups of 2 to 5 vessels deep (fig. 31) between the large pith rays. Small pores in late wood (*l. w.*) are about one-third as large as those of early wood, and with very thick walls compared with those of the large pores which are usually filled with tyloses (fig. 30, *t.*). They are arranged in 3 to 5

rather irregular radial rows which extend to the periphery of the annual ring of growth where they are exceedingly small. *Wood fibers* (fig. 31, *w. f.*) composed mainly of thick-walled elements of about 1.15 millimeters in length. In very narrow annual rings of growth, such as are usually found near the periphery of the stem of old trees, the bulk of the wood substance consists of large vessels, while the remainder is mostly composed of thin-walled wood-parenchyma fibers, which render the wood light and brittle. *Wood-parenchyma fibers* (fig. 31, *w. p. f.*) in early wood highly developed

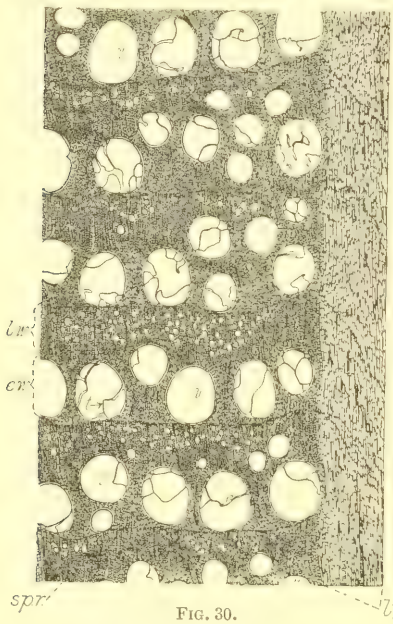

FIG. 30.

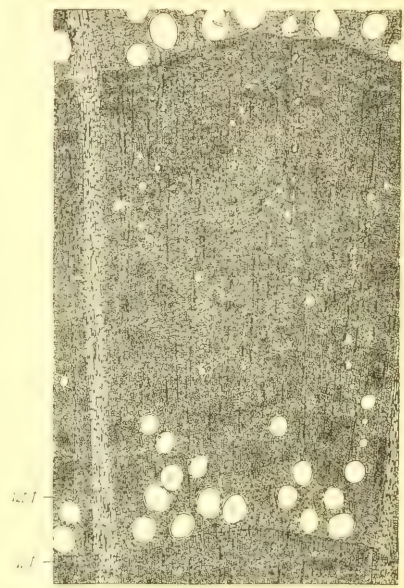

FIG. 31.

FIG. 30.—Chinquapin oak (*Quercus acuminata*). Transverse section through four entire annual rings of growth; *e. w.*, early wood; *l. w.*, late wood; *l. p. r.*, large pith ray; *s. p. r.*, small pith ray; *v.*, vessel; *t.*, tyloses. Magnified 20 diameters.

FIG. 31.—Chinquapin oak (*Quercus acuminata*). Transverse section through one entire annual ring of growth; *v.*, vessel; *w. f.*, wood fiber; *w. p. f.*, wood-parenchyma fiber. Magnified 20 diameters.

and scattered among the vessels. In late wood these fibers are found most abundantly near the small pores, and also in irregular and interrupted tangential bands. *Pith rays:* Large pith rays (fig. 30, *l. p. r.*) from 10 to 35 cells wide, and from three to four times as high and about 3 millimeters apart. Numerous small pith rays (fig. 31, *s. p. r.*) only a single cell wide and from 3 to 15 cells high.

Chinquapin oak is often sold as white oak (*Q. alba*) and is used for the same purposes, but it resembles chestnut oak (*Q. prinus*) more closely than it does white oak. It is distinguished from white oak by its dark-brown color, which contrasts more or less sharply with the reddish-brown tinge of the latter. The narrow annual rings of

growth and the proportionately larger amount of early wood than late wood of chinquapin oak will usually serve to separate it from chestnut oak.

19. Shingle Oak (*Quercus imbricaria* Michaux). (Fig. 32.)

Heartwood light brown and slightly tinged with red; sapwood although somewhat lighter in color is not clearly distinguished from the heartwood. Wood hard, heavy, close-grained and rather tough. Rate of growth moderately fast, requiring from 10 to 12 years to grow 1 inch in diameter.

Vessels (fig. 32, *v.*) in early wood (*e. w.*) occupy about one-half of the annual rings of growth. Large vessels from 3 to 6 rows deep and are more or less uniform in size and usually contain tyloses (*t.*). Their average radial diameter about 0.35 millimeter and tangential diameter about 0.25 millimeter, although in general outline the pores vary from round to elliptical or oval. In late wood (*l. w.*) they are of uniform size and only about one-eighth as large as those in early wood, and arranged in 2 or 3 single or double conspicuous radial rows. *Wood fibers* (*w. f.*) on an average 1.03 millimeters long and 0.017 millimeter wide and chiefly found between radial rows of small pores and wood-parenchyma fibers in late wood. Less than one-fifth of all the wood elements within annual rings of growth consist of wood fibers. *Wood-parenchyma fibers* (*w. p. f.*) conspicuous in late wood, and form the bulk of elements surrounding the radial rows of small vessels. They branch out from these rows into tangential bands that can be readily seen with the unaided eye. There are from 8 to 12 of these bands to each annual ring of growth. *Pith rays:* Large pith rays (*l. p. r.*) from 15 to 40 cells wide and from two to four times as high. Small pith rays (*s. p. r.*) inconspicuous and, as a rule, only a single cell wide, and from 5 to 20 cells high.

(See description under Willow oak (*Q. phellos*) for possible confusion with the wood of shingle oak.)

20. Water Oak (*Quercus nigra* Linnæus). (Fig. 33.)

Heartwood light brown tinged with yellow; sapwood rather thick and lighter colored. Wood hard, rather close-grained and not durable in contact with soil. Rate of growth moderately fast, requiring from 10 to 12 years to grow 1 inch in diameter.

Vessels (fig. 33, *v.*) in early wood (*e. w.*) arranged in from 1 to 3 tangential rows. Their tangential diameter varies from 0.14 to 0.28 millimeter and radial diameter from 0.16 to 0.35 millimeter. Vessels diminish gradually in size in late wood (*l. w.*), where they are arranged in 2 or 3 single or double radial rows, extending to the periphery of the annual rings of growth. The average diameter of the small pores is about 0.05 millimeter. They are circular and have very thick walls. *Wood fibers* (*w. f.*) vary in length from 1.08

to 1.96 millimeters, with an average length of 1.43 millimeters. Their walls are very thick and cavities small, forming the hard tissue between the radial rows of small vessels in late wood. The masses of hard fibers are intersected by very many small pith rays and by single or double tangential bands of wood-parenchyma fibers. *Wood-parenchyma fibers* (*w. p. f.*) very abundant both in early and late wood, and in the latter are arranged in numerous tangential bands, which are easily seen with a pocket lens. There are from 5 to 15 of these bands in late wood, depending upon the

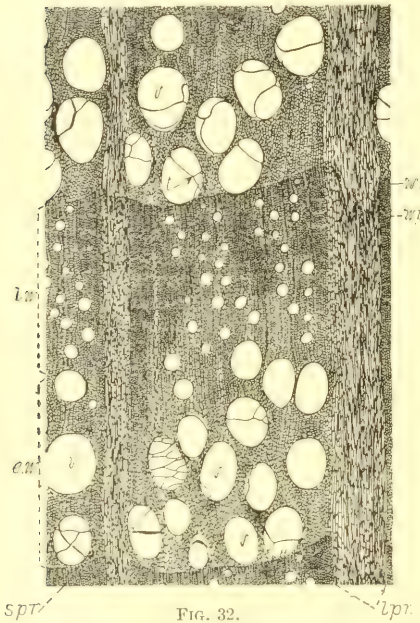

FIG. 32.

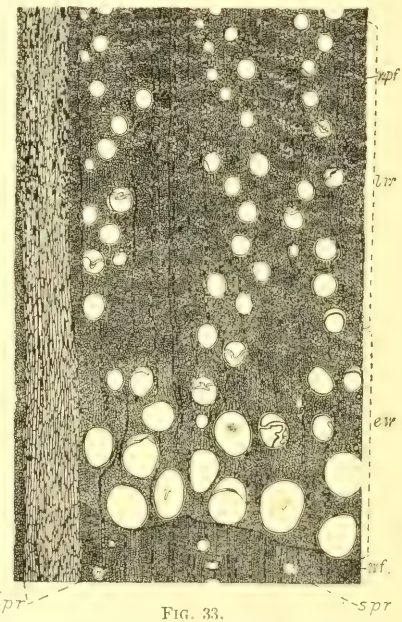

FIG. 33.

FIG. 32.—Shingle oak (*Quercus imbricaria*). Transverse section through one entire annual ring of growth; *e. w.*, early wood; *l. w.*, late wood; *l. p. r.*, large pith ray; *s. p. r.*, small pith ray; *v.*, vessel; *w. f.*, wood fiber; *w. p. f.*, wood-parenchyma fiber; *t.*, tyloses. Magnified 20 diameters.

FIG. 33.—Water oak (*Quercus nigra*). Transverse section through one entire annual ring of growth; *e. w.*, early wood; *l. w.*, late wood; *l. p. r.*, large pith ray; *s. p. r.*, small pith ray; *v.*, vessel; *w. f.*, wood fiber; *w. p. f.*, wood-parenchyma fiber. Magnified 20 diameters.

width of the annual rings of growth. *Pith rays:* Large pith rays (*l. p. r.*) from 15 to 40 cells wide, from three to four times as high, and from 3 to 5 millimeters apart. The small pith rays (*s. p. r.*) are conspicuous, but only 1 cell wide and from 5 to 20 cells high.

21. Turkey Oak (*Quercus catesbæi* Michaux). (Fig. 34.)

Heartwood light brown tinged with red or yellow; sapwood thick and somewhat lighter colored, though occasionally quite yellowish. Wood rather hard, heavy, medium close-grained and not very durable in contact with the soil. This species usually grows in dry uplands, where the rate of diameter increase is moderately slow, requiring from 10 to 15 years to grow 1 inch in diameter.

Vessels: Large vessels (fig. 34, *v.*) in early wood (*e. w.*) from 1 to 3 rows deep, varying in diameter from 0.26 to 0.40 millimeter, but gradually diminishing in size toward the periphery of the annual ring of growth. Vessels in late wood (*l. w.*) vary from 0.10 to 0.20 millimeter in diameter and have very thick walls compared with those in early wood. There are from 1 to 3 irregular, interrupted radial rows of small pores between the large pith rays. *Wood fibers* (*w. f.*) thick-walled and almost entirely confined to late wood, where they are scattered in small groups. *Wood fibers* on an average

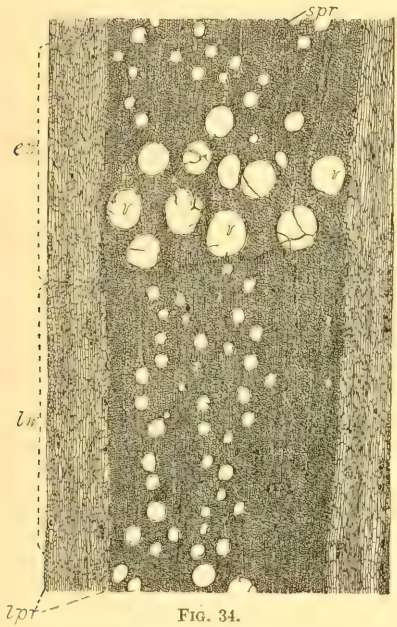

FIG. 34.

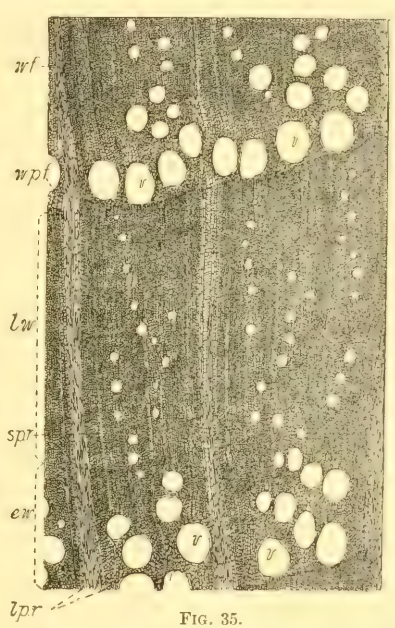

FIG. 35.

FIG. 34.—Turkey oak (*Quercus catesbæi*). Transverse section through parts of two annual rings of growth; *e. w.*, early wood; *l. w.*, late wood; *l. p. r.*, large pith ray; *s. p. r.*, small pith ray; *v.*, vessel. Magnified 20 diameters.

FIG. 35.—Spanish oak (*Quercus digitata*). Transverse section through one entire annual ring of growth; *e. w.*, early wood; *l. w.*, late wood; *l. p. r.*, large pith ray; *s. p. r.*, small pith ray; *v.* vessel; *w. f.*, wood fiber; *w. p. f.*, wood-parenchyma fiber. Magnified 20 diameters.

1.47 millimeters long and about 0.026 millimeter wide. *Wood-parenchyma fibers* abundant both in early and late wood, in the latter surrounding the smaller vessels and forming irregular, inconspicuous, and much interrupted tangential bands. Usually from 6 to 10 of these bands within an annual layer of growth. *Pith rays:* Large pith rays (*l. p. r.*) from 20 to 45 cells wide, from two to four times as high, and from 2 to 4 millimeters apart. Cells in the small pith rays (*s. p. r.*) are large and the rays themselves quite conspicuous.

22. Spanish Oak (*Quercus digitata* (Marsh) Sudworth). (Fig. 35.)

Heartwood reddish; sapwood thick and lighter colored, with a slightly brownish tinge. Heartwood resembles that of red oak, except that it is tinged brighter red. It is light in weight, though

moderately hard and strong, not durable in contact with the soil, and moderately fast growing, requiring approximately 8 years to grow 1 inch in diameter.

Vessels (fig. 35, *v.*) in early wood (*e. w.*) form a single interrupted row. They are elliptical or oval and vary from 0.15 to 0.25 millimeter in diameter. Small pores on an average about 0.075 millimeter in diameter, becoming smaller in late wood (*l. w.*), where they form single radial and nearly parallel rows extending through the annual rings of growth. *Wood fibers* (*w. f.*) very numerous in early wood, where they occur in small groups among the thinner-walled elements and gradually increase in number in late wood. In transverse section they are pentagonal in outline and have moderately thick walls and small cavities. The individual fibers vary from 1.08 millimeters to 2 millimeters in length, with an average width of 0.024 millimeter. The wood of this species contains fibers having the greatest average length (1.65 millimeters). *Wood-parenchyma fibers* (*w. p. f.*) arranged in concentric lines around the vessels in early wood and bordering the small pores in late wood. They also form irregular, narrow tangential bands in late wood. There are from 10 to 12 of these bands in annual rings of growth of moderately fast-growing trees. *Pith rays:* Large pith rays (*l. p. r.*) on an average about 20 cells wide and from two to three times as high, and from 2 to 4 millimeters apart. The height and width of the rays vary considerably, depending upon the age and size of the trees. Small pith rays (*s. p. r.*) are numerous, and usually only 1 cell wide and from 8 to 16 cells high.

The wood of Spanish oak is occasionally confused with red oak (*Q. rubra*), but is distinguished by having fewer and less-pronounced pith rays than red oak.

23. Blackjack Oak (*Quercus marilandica* Muenchh.). (Fig. 36.)

Heartwood dark brown; sapwood somewhat lighter colored and with a yellowish tinge. Wood hard, heavy, and not durable in contact with soil. Rate of growth compares with that of post oak.

Vessels (fig. 36, *v.*) in early wood (*e. w.*) usually 4 rows deep and invariably filled with tyloses (*t.*), round or seldom elliptical in outline and varying from 0.2 to 0.4 millimeter in diameter. Vessels in late wood (*l. w.*) about one-sixth as large as those in early wood, and arranged in irregular or branched radial rows. Small pores uniform in size with very thick walls. *Wood fibers* (*w. f.*) have very thick walls and rather small cavities. They vary from 1.04 to 1.63 millimeters in length, with an average length of 1.38 millimeters, and are approximately 0.027 millimeter wide. *Wood-parenchyma fibers* (*w. p. f.*) are scattered in short, irregular, tangential bands or in small groups in late wood and surrounding the large and small vessels.

In radial section these elements may be seen with the aid of a microscope in distinct parallel lines. *Pith rays:* Large pith rays (*l. p. r.*) from 10 to 40 cells wide and from two to four times as high. Rays in the wood of trees grown in dry upland are more highly developed than those in wood grown in rich moist lowlands. Small pith rays (*s. p. r.*) are exceedingly numerous and usually only one cell wide, occasionally 2 or 3, and from 10 to 20 cells high.

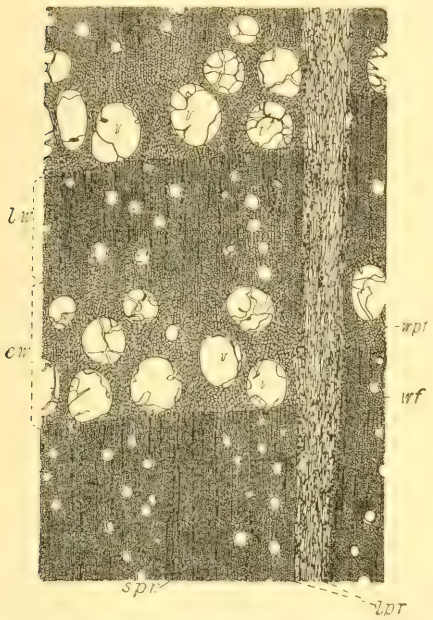

FIG. 36.

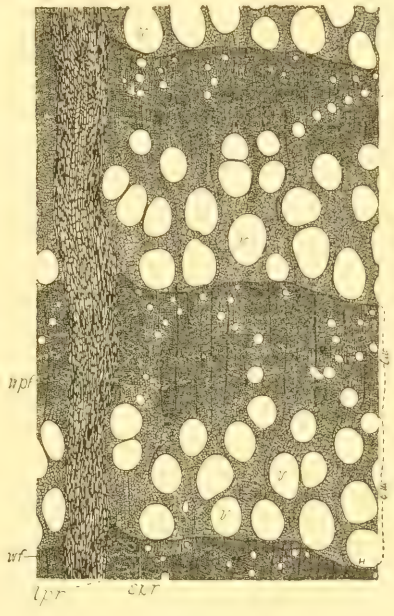

FIG. 37.

FIG. 36.—Blackjack (*Quercus marilandica*). Transverse section through one annual ring of growth; *e. w.*, early wood; *l. w.*, late wood; *l. p. r.*, large pith ray; *s. p. r.*, small pith ray; *v.*, vessel; *w. f.*, wood fiber; *w. p. f.*, wood-parenchyma fiber. Magnified 20 diameters.

FIG. 37.—Scarlet oak (*Quercus coccinea*). Transverse section through two entire annual rings of growth; *e. w.*, early wood; *l. w.*, late wood; *l. p. r.*, large pith ray; *s. p. r.*, small pith ray; *v.*, vessel; *w. f.*, wood fiber; *w. p. f.*, wood-parenchyma fiber. Magnified 20 diameters.

24. Scarlet Oak (*Quercus coccinea* Muenchh.). (Fig. 37.)

Heartwood reddish brown or slightly tinged with yellow; sapwood thick and much lighter colored. Wood hard, heavy, and tough and in its general properties and rate of growth compares with that of yellow oak. Approximately one-half of the annual ring of growth consists of early wood.

Vessels (fig. 37, *v.*) in early wood (*e. w.*) form a conspicuous ring from 3 to 5 rows deep. They are either round, elliptical, or oval and are from 0.2 to 0.4 millimeter in diameter; gradually diminishing in size in late wood (*l. w.*). In late wood they are arranged in single though more or less irregular radial rows, visible with a pocket lens or even with the unaided eye when perfectly smooth sections are

prepared. Walls of vessels in late wood are very thick, averaging 0.05 millimeter. There are from 2 to 4 conspicuous radial rows of small vessels between the large pith rays. *Wood fibers* (*w. f.*) are almost entirely wanting in early wood. They form a rectangular group in late wood between the radial lines of small vessels and tangential bands of wood-parenchyma fibers. They have an average length of 1.49 millimeters and are approximately 0.023 millimeter wide. The longest individual fiber was found in the wood of this species, measuring 2.08 millimeters. *Wood-parenchyma fibers* (*w. p. f.*) are arranged principally in numerous tangential bands in late wood, where there are from 5 to 15 of such rows within an annual layer of growth of average width. *Pith rays:* Large pith rays (*l. p. r.*) are about 30 cells wide and from three to four times as high. Small pith rays (*s. p. r.*) only a single cell wide and vary in height from several to 12 or 15 cells.

Scarlet oak is often mistaken for yellow oak (*Q. velutina*), from which it can be recognized by its more or less reddish tinge, yellow oak having a yellowish tinge. Scarlet oak wood is sometimes confused also with red oak (*Q. rubra*), from which it is distinguished by its more pronounced reddish color and narrow annual rings of growth, red oak wood having a pale red tinge and wide rings of growth.

25. Bluejack Oak (*Quercus brevifolia* Sargent). (Fig. 38.)

Heartwood light brown and occasionally tinged with red; sapwood thick and dark brown and easily distinguished from the heartwood. Wood hard, strong, moderately close-grained, and not durable in contact with the soil.

Vessels (fig. 38, *v.*) in early wood (*e. w.*) from 0.15 to 0.25 millimeter in diameter. They are from 3 to 5 rows deep and much interrupted, giving the appearance of a succession of groups of vessels. Vessels diminish in size to less than 0.05 millimeter in diameter in late wood (*l. w.*), forming from 3 to 5 irregular radial rows and having thicker walls than those in early wood. *Wood fibers* (*w. f.*) have an average length of 1.12 millimeters. They are not abundant in early wood, but form the bulk of the elements between the radial rows of small vessels in late wood. *Wood-parenchyma fibers* (*w. p. f.*) abundant both in early and late wood. They surround the large and small vessels, and in late wood occur in numerous, inconspicuous, irregular tangential bands. *Pith rays:* Large pith rays (*l. p. r.*) are from 15 to 40 cells wide, from three to four times as high and 1 to 4 millimeters apart. Small pith rays (*s. p. r.*) are conspicuous in transverse sections, though seldom more than 1 cell wide and from 10 to 20 cells high.

26. Pin Oak (*Quercus palustris* Muenchh.). (Fig. 39.)

Heartwood dark brown tinged with red; sapwood somewhat lighter, though occasionally slightly darker in color than the heartwood.

Wood hard, heavy, tough, and coarse-grained. Rate of growth and durability similar to that of willow oak.

Vessels (fig. 39, *v.*) in early wood (*e. w.*) arranged in rather small groups between the large pith rays, and numbering from 6 to 12, nearly round pores, to each group; pores from 0.15 to 0.25 millimeter in diameter. Small pores in late wood (*l. w.*) occur in rather irregular, interrupted radial rows, which originate near the middle of the late wood and extend to the periphery of the annual ring of growth. There are usually 3, but occasionally from 5 to 7, radial

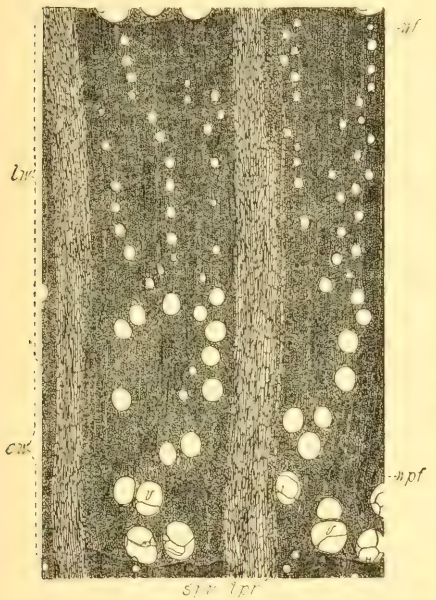

FIG. 38.

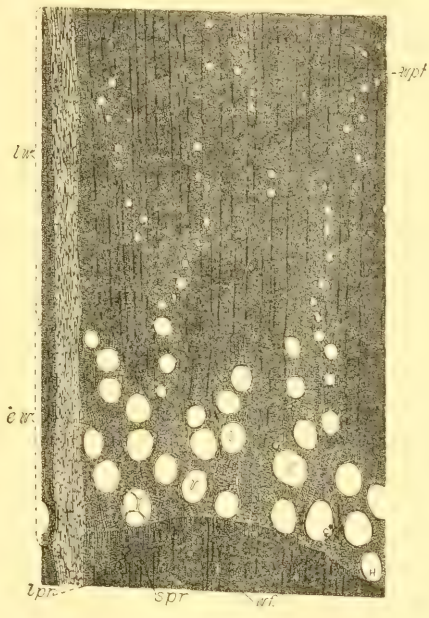

FIG. 39.

FIG. 38.—Bluejack oak (*Quercus brevifolia*). Transverse section through one entire annual ring of growth; *e. w.*, early wood; *l. w.*, late wood; *l. p. r.*, large pith ray; *s. p. r.*, small pith ray; *v.*, vessel; *w. f.*, wood fiber; *w. p. f.*, wood-parenchyma fiber. Magnified 20 diameters.

FIG. 39.—Pin oak (*Quercus palustris*). Transverse section through one entire annual ring of growth; *e. w.*, early wood; *l. w.*, late wood; *l. p. r.*, large pith ray; *s. p. r.*, small pith ray; *v.*, vessel; *w. f.*, wood fiber; *w. p. f.*, wood-parenchyma fiber. Magnified 20 diameters.

rows of small pores between the large pith rays. *Wood fibers* (*w. f.*) in early wood very sparse, but they form the bulk of the late wood. They are about 1.35 millimeters long and 0.017 millimeter wide. The cell walls are usually quite thin. *Wood-parenchyma fibers* (*w. p. f.*) abundant both in early and late wood. In the latter they are arranged in numerous distinct narrow bands, depending upon the width of the annual rings of growth. *Pith rays:* Large pith rays (*l. p. r.*) are from 0.25 to 0.5 millimeter wide, from 7 to 15 millimeters high, and from 2 to 3 millimeters apart. Small pith rays (*s. p. r.*) numerous, only a single cell wide and from 10 to 20 cells high.

Pin-oak wood is very similar in general appearance to red oak (*Q. rubra*) and from which it can be distinguished only with difficulty. The pores of pin oak are less numerous and often considerably smaller than those in red oak.

27. Texan Oak (*Quercus texana* Buckley). (Fig. 40.)

Heartwood reddish brown, closely resembling that of red oak; sapwood light and sometimes tinged with yellow. Wood hard, heavy, close-grained, moderately tough and not durable in contact with soil. Rate of growth equal to that of Spanish oak.

Vessels (fig. 40, *v.*) in early wood (*e. w.*) numerous and usually from 3 to 5 (rarely 2) rows deep. They are round or slightly compressed tangentially, and are from 0.15 to 0.3 millimeter in diameter, varying but little in size between the inner and outer rows. Pores are abruptly smaller in late wood (*l. w.*), being less than one-third as wide as those in early wood and having quite thick walls. They are arranged in from 2 to 4 single or double radial rows extending to the periphery of the annual ring of growth. *Wood fibers* (*w. f.*) are confined almost entirely to late wood, where they form dense masses between the radial rows of small vessels. They average about 1.37 millimeters long and approximately 0.023 millimeter wide, and have thick walls and small cavities. *Wood-parenchyma fibers* (*w. p. f.*) abundant in early wood, where they occur in numerous irregular, interrupted, tangential bands surrounding the vessels. Crystals of calcium oxalate very numerous in these elements. *Pith rays:* Large pith rays (*l. p. r.*) are from 20 to 30 cells wide, from three to four times as high and about 3 millimeters apart. Small rays (*s. p. r.*) conspicuous, but they are seldom more than 1 cell wide and from 5 to 18 cells high.

The wood of Texan oak is the chief substitute for red oak (*Q. rubra*) and it is difficult to distinguish from the latter species. A slight yellowish tinge of Texan oak and its narrow annual rings of growth will usually serve to separate it from the red oak.

28. Yellow Oak (*Quercus velutina* Lamarck). (Fig. 41.)

Heartwood reddish brown or tinged with yellow; sapwood thin and almost white. Wood moderately hard, heavy, quite strong, rather coarse, straight-grained and not durable in contact with the soil. Rate of growth moderately slow, requiring from 12 to 14 years to grow 1 inch in diameter.

Vessels (fig. 41, *v.*) in early wood (*e. w.*) from 3 to 5 rows deep, and elliptical in shape, being from 0.2 to 0.5 millimeter in tangential and from 0.3 to 0.7 millimeter in radial diameter. They gradually diminish in size in late wood (*l. w.*), forming single irregular radial rows of vessels about 0.06 millimeter in diameter. Occasionally these radial rows do not reach the periphery of the annual rings of

growth. *Wood fibers* (*w. f.*) compose the bulk of the elements in late wood and average 1.3 millimeters long and 0.022 wide. *Wood-parenchyma fibers* (*w. p. f.*) abundant in late wood and are arranged in concentric lines around the large and small vessels. These can best be seen in radial sections as distinct uninterrupted parallel lines. Such fibers also arranged in numerous single and much interrupted tangential bands or in isolated groups which are not conspicuous on a transverse section. *Pith rays:* Large pith rays (*l. p. r.*) are from 20 to 40 cells wide, from two to four times as high and on an

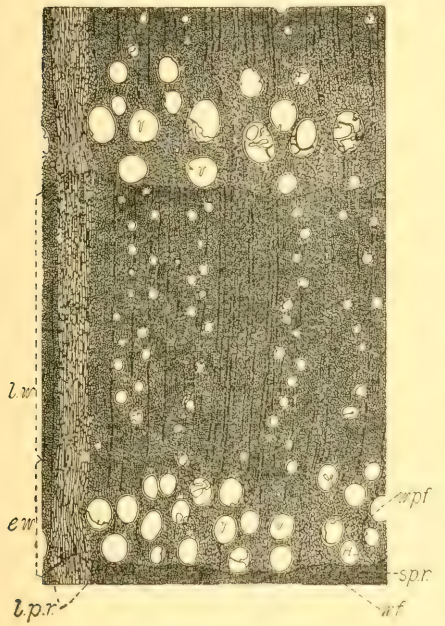

FIG. 40.

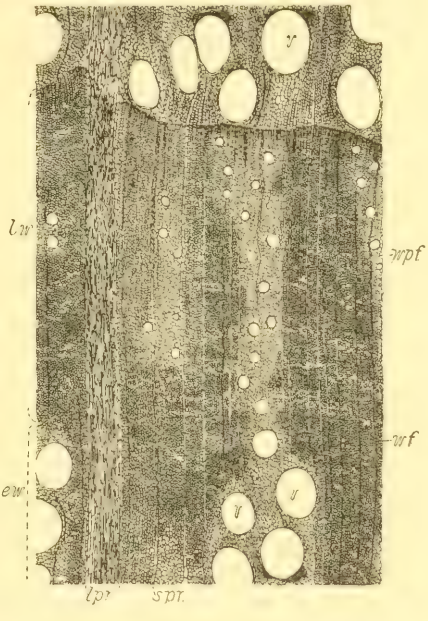

FIG. 41.

FIG. 40.—Texan oak (*Quercus texana*). Transverse section through one entire annual ring of growth; *e. w.*, early wood; *l. w.*, late wood; *l. p. r.*, large pith ray; *s. p. r.*, small pith ray; *v.*, vessel; *w. f.*, wood fiber; *w. p. f.*, wood-parenchyma fiber. Magnified 20 diameters.

FIG. 41.—Yellow oak (*Quercus velutina*). Transverse section through parts of two annual rings of growth; *e. w.*, early wood; *l. w.*, late wood; *l. p. r.*, large pith ray; *s. p. r.*, small pith ray; *v.*, vessel; *w. f.*, wood fiber; *w. p. f.*, wood-parenchyma fiber. Magnified 20 diameters.

average of 3 millimeters apart. Small pith rays (*s. p. r.*) are from 1 to 3 cells (rarely more than 1 cell) wide and from 3 to 18 cells high.

For possible confusion of this wood with scarlet oak (*Q. coccinea*) see description of the latter.

29. Red Oak (*Quercus rubra* Linnæus). (Fig. 42.)

Heartwood light red or slightly tinged with brown; sapwood thin and lighter colored. Wood hard, heavy, moderately strong, close-grained, and not durable in contact with soil. This is among the fastest-growing oaks, increasing in diameter at the rate of 1 inch

in about 8 or 10 years. Next to white oak, this is the most common oak on the market in the form of manufactured lumber. It is extensively used in the manufacture of furniture and for interior finish. The "silver grain" (large pith rays) is very conspicuous when the logs are quarter-sawed. The wood varies remarkably in different localities.

Vessels (fig. 42, *v.*) in early wood (*e. w.*) usually from 3 to 5 rows deep. They are either round or elliptical and about 0.25 millimeter in diameter. In late wood (*l. w.*) the small vessels have thicker

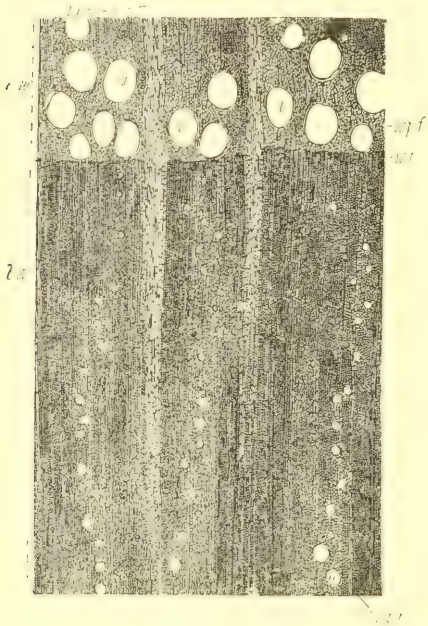

FIG. 42.

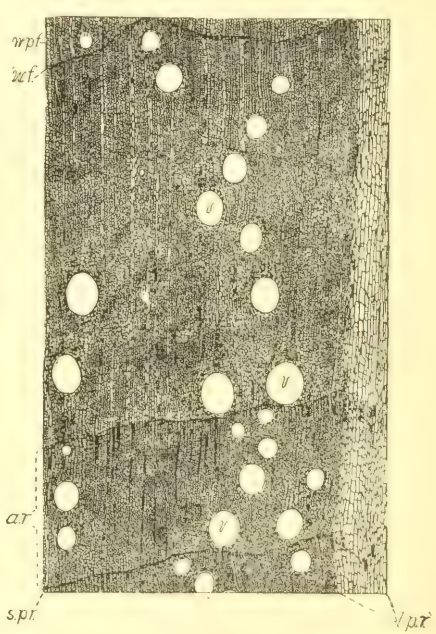

FIG. 43.

FIG. 42.—Red oak (*Quercus rubra*). Transverse section through parts of two annual rings of growth; *e. w.*, early wood; *l. w.*, late wood; *l. p. r.*, large pith ray; *s. p. r.*, small pith ray; *v.*, vessel; *w. f.*, wood fiber; *w. p. f.*, wood-parenchyma fiber. Magnified 20 diameters.

FIG. 43.—California live oak (*Quercus agrifolia*). Transverse section through two annual rings of growth; *a. r.*, annual ring; *l. p. r.*, large pith ray; *s. p. r.*, small pith ray; *v.*, vessel; *w. f.*, wood fiber; *w. p. f.*, wood-parenchyma fiber. Magnified 20 diameters.

walls and form from 3 to 6 radial rows extending across the width of the annual rings of growth. The size of the vessels gradually diminishes from the early to the late wood. This is a constant character and may be relied upon in separating the red oak from the white oak. In the latter the pores diminish abruptly. The average diameter of small vessels in late wood is about 0.08 millimeter. *Wood fibers* (*w. f.*) compose the bulk of late wood. They have rather thick walls and moderately large cavities. The average length of the fibers is 1.19 millimeters and the average width 0.018 millimeter. *Wood-parenchyma fibers* (*w. p. f.*) are scattered rather

irregularly throughout the annual rings of growth and surround the large and small vessels. They also form narrow tangential bands in the late wood. *Pith rays:* Large pith rays (*l. p. r.*) are usually from 1 to 3 millimeters apart. Small pith rays (*s. p. r.*) are very numerous and usually but 1 cell wide.

The wood of this oak may be confused with Spanish oak (*Q. digitata*), scarlet oak (*Q. coccinea*), yellow oak (*Q. velutina*), pin oak (*Q. palustris*), and Texan oak (*Q. texana*). See description of each for special distinctions.

30. California Live Oak (*Quercus agrifolia* Nees von Esenbeck). (Fig. 43.)

Heartwood light brown tinged with red; sapwood thick and slightly darker colored. Wood hard, heavy, close-grained, and rather brittle. Rate of growth exceedingly slow, requiring from 15 to 30 years to increase 1 inch in diameter.

Vessels (fig. 43, *v.*) arranged in 2 or 3 radial rows between the large pith rays, showing very little contrast between early (*e. w.*) and late wood (*l. w.*). The absence of distinct tangential rows of pores renders it difficult to obtain figures on rate of growth. Vessels formed during the beginning of the growing season are usually larger than those formed later. Occasionally, however, the pores in the middle of the annual rings of growth are larger than near the inner boundary. Large vessels vary from 0.15 to 0.25 millimeter, while those near the periphery of the annual ring are only about one-half as large, and usually round, though sometimes slightly elongated radially. *Wood fibers* (*w. f.*) are, on an average, 1.34 millimeters long and have exceedingly thick walls and very small cavities. They are regularly arranged throughout the entire width of the annual ring. *Wood-parenchyma fibers* (*w. p. f.*) in early wood chiefly surround vessels. Near the periphery of the annual ring of growth these elements are arranged in numerous irregular, tangential bands clearly distinguishable under the compound microscope. The wood of this species contains more wood-parenchyma fibers per unit area than that of any other oak. It also contains a great many crystals of calcium oxalate. *Pith rays:* Large pith rays (*l. p. r.*) are from 15 to 30 cells wide, from three to four times as high, and from 3 to 6 millimeters apart. Small pith rays (*s. p. r.*) are exceedingly numerous and are composed of unusually large cells.

31. Highland Live Oak (*Quercus wislizeni* A. de Candolle.) (Fig. 44.)

Heartwood light reddish brown; sapwood thick and somewhat lighter colored. Wood hard, heavy, tough, moderately close-grained, and very durable in contact with soil. It is an evergreen oak with rather indistinct annual rings of growth, the boundaries of which

can only be seen with the aid of a pocket lens magnifying 6 or 8 diameters. Rate of growth moderately slow, requiring from 12 to 15 years to grow 1 inch in diameter.

Vessels (fig. 44, *v.*) in early wood (*e. w.*) from 1 or 2 interrupted tangential rows, gradually diminishing in size in late wood (*l. w.*), where they are arranged radially in single or double rows across the annual rings of growth. The average width of vessels in late wood is about one-half of those in early wood. There are 2 or 3 distinct radial rows of small vessels between the large pith rays. Walls of

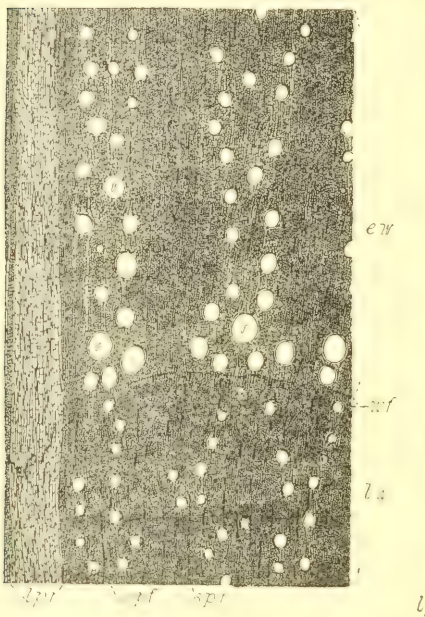

FIG. 44.

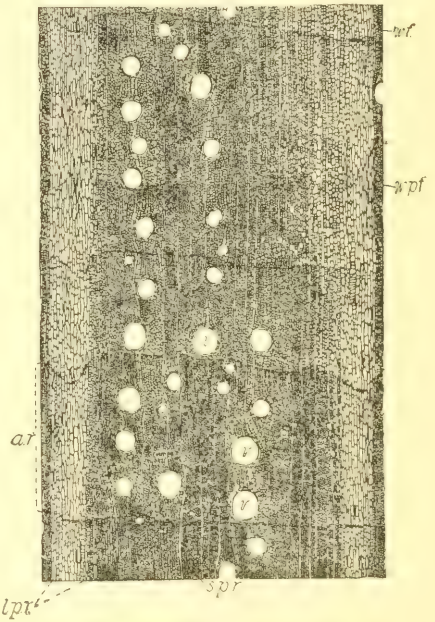

FIG. 45.

FIG. 44.—Highland oak (*Quercus wislizeni*). Transverse section through parts of two annual rings of growth; *e. w.*, early wood; *l. w.*, late wood; *l. p. r.*, large pith ray; *s. p. r.*, small pith ray; *v.*, vessel; *w. f.*, wood fiber; *w. p. f.*, wood-parenchyma fiber. Magnified 20 diameters.

FIG. 45.—Canyon live oak (*Quercus chrysolepis*). Transverse section through three entire annual rings of growth; *a. r.*, annual ring; *l. p. r.*, large pith ray; *s.p. r.*, small pith ray; *v.*, vessel; *w. f.*, wood fiber; *w. p. f.*, wood-parenchyma fiber. Magnified 20 diameters.

vessels very thick, especially in the outer part of late wood. *Wood fibers* (*w. f.*) about 1.16 millimeters long and 0.019 millimeter wide, with thick walls and exceedingly small cavities. *Wood-parenchyma fibers* (*w. p. f.*) more or less evenly distributed throughout the annual layers of growth. Tangential bands not clearly visible with an ordinary pocket lens. Under the microscope they are shown to be irregular and greatly interrupted by wood fibers. *Pith rays:* Large pith rays (*l. p. r.*) about 30 cells wide and from 2 to 3 millimeters apart. Small pith rays (*s. p. r.*) seldom more than a single cell wide and from 8 to 12 cells high.

32. Canyon Live Oak (*Quercus chrysolepis* Liebmann). (Fig. 45.)

Heartwood light brown or sometimes tinged with red; sapwood (generally quite thick) is sometimes darker colored than the heartwood. Wood very hard, heavy, strong, and not durable in contact with soil. In manner and rate of growth this species approaches the eastern live oak.

Vessels: The manner in which the vessels (fig. 45, *v.*) in the annual rings of growth are grouped corresponds somewhat to that in the eastern live oak, except that in the former they are more numerous, particularly the smaller pores near the periphery of the annual ring of growth (*a. r.*). Vessels are usually round and vary from 0.08 to 0.2 millimeter in diameter. The walls of small pores are very thick and their cavities small. *Wood fibers* (*w. f.*) uniformly distributed throughout the annual rings of growth. They average 1.2 millimeters long and about 0.02 millimeter wide. The cell walls are very thick and the cavities small. *Wood-parenchyma fibers* (*w. p. f.*) are scattered irregularly among the wood fibers. Near the periphery of the annual rings they are arranged in short tangential bands, seldom more than one cell in width. *Pith rays:* Large pith rays (*l. p. r.*) are from 20 to 35 cells wide, from two to four times as high, and from 0.3 to 0.8 millimeter apart.

33. Blue Oak (*Quercus douglasii* Hooker and Arnott). (Fig. 46.)

Heartwood dark brown or sometimes nearly black when exposed; sapwood rather thick and of much lighter color. Wood moderately hard, heavy, coarse-grained, often very brittle, and not durable in contact with soil. Rate of growth slow, requiring from 15 to 20 years to grow 1 inch in diameter.

Vessels (fig. 46, *v.*) vary from 0.05 to 0.25 millimeter in diameter. Individual vessels often extend across the entire width of the annual ring of growth (*a. r.*). These as well as the smaller vessels in late wood are surrounded by wood-parenchyma fibers, allowing comparatively little space for the development of thick-walled wood fibers. Vessels have very thick walls, particularly the small ones in late wood. *Wood fibers* (*w. f.*) invariably found only near the periphery of wide annual rings of growth. They vary from 0.96 to 1.38 millimeters in length with an average length of 1.13 millimeters. *Wood-parenchyma fibers* (*w. p. f.*) scattered uniformly throughout, but are chiefly found bordering the vessels. They contain numerous crystals of calcium oxalate. *Pith rays:* Large pith rays (*l. p. r.*) very numerous, from 15 to 35 cells wide, from two to four times as high, and from 1.5 to 3 millimeters apart. Small pith rays (*s. p. r.*) only a single cell wide and from 5 to 15 cells high; they are very irregular on account of the small pores which they avoid.

(For possible confusion of this wood with that of valley oak (*Q. lobata*) see description of the latter.)

34. Tanbark Oak (*Quercus densiflora* Hooker and Arnott). (Fig. 47.)

Heartwood light brown or tinged with red; sapwood thick, dark brown or often tinged with yellow. Wood very hard, heavy, strong, and close-grained. Old and slow-growing trees produce wood that is very brittle and not durable in contact with soil. Rate of growth slow, requiring from 15 to 20 years for the average tree to grow 1 inch in diameter.

Vessels (fig. 47, *v.*) arranged in rather wide radial rows which can be easily seen on a smooth transverse section with the unaided eye.

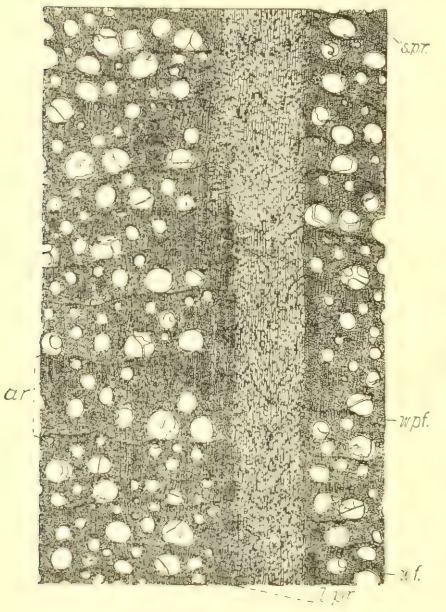

FIG. 46.

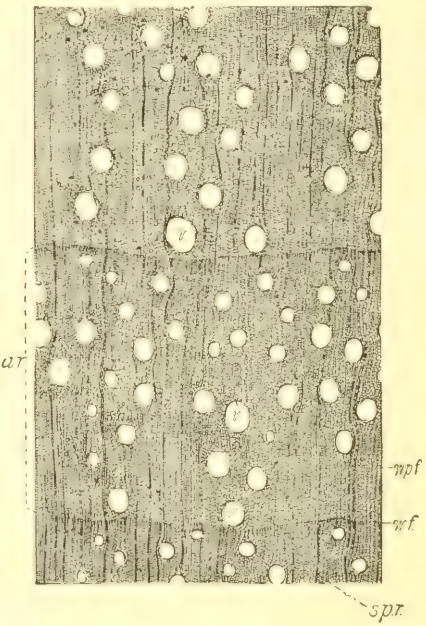

FIG. 47.

FIG. 46.—(California) Rock oak (*Quercus douglasii*). Transverse section through 12 annual rings of growth, *a. r.*, annual ring; *l. p. r.*, large pith ray; *s. p. r.*, small pith ray; *v.*, vessel; *w. f.*, wood fiber; *w. p. f.*, wood-parenchyma fiber. Magnified 20 diameters.

FIG. 47.—(California) Tanbark oak (*Quercus densiflora*). Transverse section through one entire annual ring of growth; *a. r.*, annual ring; *s. p. r.*, small pith ray; *v.*, vessel; *w. f.*, wood fiber; *w. p. f.*, wood-parenchyma fiber. Magnified 20 diameters.

There is no sharp contrast between early and late wood. The boundaries of annual rings of growth (*a. r.*) are indistinctly marked by a few rows of radially compressed wood fibres. Although vessels are usually larger in early wood, they are sometimes larger in late wood and gradually increase in number toward the periphery where the radial rows are branched. The diameters of the pores vary from 0.05 to 0.3 millimeter with an average of about 0.15 millimeter. *Wood fibers* (*w. f.*) average 1.23 millimeters long and are most abundant in early wood and near the middle of the annual

rings. *Wood-parenchyma fibers* (*w. p. f.*) very abundant between the large pores, forming conspicuous radial rows across the entire width of the annual rings of growth. They are also arranged in single or double conspicuous tangential bands. The late wood is largely composed of small pores and wood-parenchyma fibers. *Pith rays*: Large pith rays (*l. p. r.*) from 25 to 40 cells wide and from two to four times as high. Small pith rays (*s. p. r.*) are only a single cell wide and from 30 to 40 cells high. In a transverse section they are very conspicuous when viewed under the compound microscope. The cells composing the rays contain considerable starch, tannin, and numerous crystals of calcium oxalate.

35. Live Oak (*Quercus virginiana* Miller). (Fig. 48.)

Heartwood light brown and tinged with yellow; sapwood very thin and cream colored or sometimes nearly white. Wood very hard, heavy, strong, and very durable in contact with soil. Rate of growth very slow, requiring on an average from 15 to 20 years to grow 1 inch in diamater.

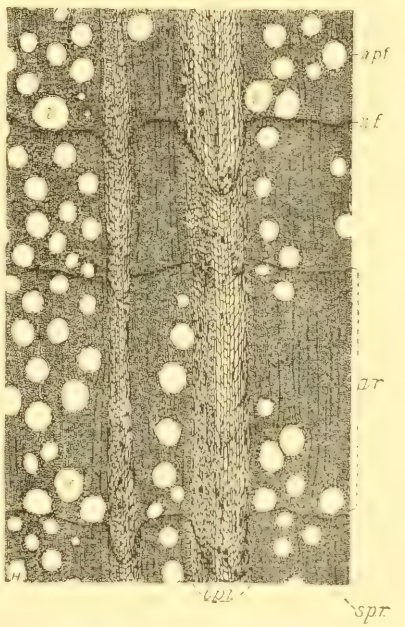

FIG. 48.—Live oak (*Quercus virginiana*). Transverse section through two entire annual rings of growth; *a. r.*, annual ring; *l. p. r.*, large pith ray; *s. p. r.*, small pith ray; *v.*, vessel; *w. f.*, wood fiber; *w. p. f.*, wood-parenchyma fiber. Magnified 20 diameters.

Vessels (fig. 48, *v.*) in early and late wood usually round and vary from 0.1 to 0.25 millimeter in diameter. Radial rows of small vessels so common in most American oaks are generally absent. Walls very thick, especially near the periphery of the annual rings of growth (*a. r.*). *Wood fibers* (*w. f.*) uniformly distributed and vary in length from 0.83 to 1.79 millimeters and about 1.39 millimeters in diameter. Walls very thick and the cavities small, thus giving to the wood its peculiar hardness and toughness which make it so valuable for construction purposes. The outer edge of each annual ring of growth is marked by 2 or 3 layers of wood fibers which are very much flattened radially. *Wood-parenchyma fibers* (*w. p. f.*) occur in concentric bands around the larger vessels, but they are also arranged in irregular and inconspicuous tangential bands in late wood. The number of these bands varies with the width of the annual rings.

There are on an average about 10 such bands to each millimeter in radial distance. *Pith rays:* Large pith rays (*l. p. r.*) are from 25 to 50 cells wide, from two to four times as high, and from 1 to 3 millimeters apart. The small pith rays (*s. p. r.*) are seldom more than 1 cell wide and from a few to 12 or 15 cells high.

(For possible confusion of this wood with that of laurel oak (*Q. laurifolia*) see description of the latter.)

TABLE 1.—*The lengths and widths of wood fibers of the most important North American oaks.*

Species.	Length.			Width.		
	Average.	Maximum.	Minimum.	Average.	Maximum.	Minimum.
	Mm.	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*
Quercus laurifolia	1.342	1.875	0.958	0.021	0.027	0.019
gambelii	1.158	1.417	.875	.018	.019	.015
garryana	1.300	1.625	1.083	.018	.019	.015
lobata	1.242	1.542	.792	.020	.023	.015
reticulata	1.063	1.333	.750	.017	.019	.015
arizonica	.921	1.417	.708	.018	.019	.015
minor	.979	1.250	.833	.014	.015	.012
platanoides	1.038	1.250	.750	.017	.019	.012
emoryi	1.121	1.500	.833	.020	.023	.019
californica	1.213	1.458	.833	.022	.027	.019
alba	1.267	1.625	1.000	.018	.019	.015
macrocarpa	1.354	1.667	1.042	.021	.023	.019
breviloba	1.229	1.417	.875	.018	.023	.015
phellos	1.521	1.875	1.167	.021	.027	.015
lyrata	1.325	1.708	1.000	.022	.023	.019
michauxii	1.538	1.792	1.083	.021	.023	.019
prinus	1.308	1.667	.958	.020	.023	.019
acuminata	1.154	1.500	.917	.018	.023	.015
imbricaria	1.033	1.417	.667	.017	.019	.015
nigra	1.433	1.958	1.083	.018	.023	.015
catesbæi	1.471	1.833	1.208	.026	.031	.023
digitata	1.646	2.000	1.083	.024	.027	.019
marilandica	1.375	1.625	1.042	.022	.027	.019
coccinea	1.488	2.083	1.000	.023	.031	.019
brevifolia	1.121	1.375	.792	.018	.023	.015
palustris	1.354	1.625	1.042	.017	.019	.015
texana	1.367	1.583	1.167	.023	.031	.015
velutina	1.300	1.667	.958	.022	.027	.015
rubra	1.188	1.458	.708	.018	.019	.015
agrifolia	1.358	1.625	1.042	.022	.031	.015
wislizeni	1.163	1.375	.917	.019	.019	.019
chrysolepis	1.204	1.542	.917	.020	.023	.015
douglasii	1.133	1.375	.958	.018	.023	.015
densiflora	1.225	1.458	.958	.027	.031	.023
virginiana	1.388	1.792	.833	.016	.019	.015

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